DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

BULLETIN 701

GEOTHERMAL DATA OF THE UNITED STATES

INCLUDING MANY ORIGINAL DETERMINATIONS OF UNDERGROUND TEMPERATURE

BY

N. H. DARTON

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By N. H. Darton.

INTRODUCTION.

The purpose of this report is to present all available published data bearing on the rate of increase of underground temperature with increasing depth in the United States, together with several hundred original observations by myself and my associates. A canvass of the governmental, State, and serial publications has yielded many records of temperature of flowing wells and also a few observations made with thermometers in borings and deep mines. Additional data on temperature of flows have been given by correspondents. Some of the data, especially those relating to flows from wells, may not be reliable, and as a rule these could not be discriminated. Many records are omitted because no facts are available as to the source of flow.

During extended investigations of the geology of underground waters in many parts of the United States I and my assistants have had opportunity to observe the temperature of flows and to sink thermometers in deep borings. One very important contribution has come from an associate, J. E. Todd, who recorded the temperature of flows from a large number of wells in central-eastern South Dakota.

Mr. C. E. Van Orstrand, of the U. S. Geological Survey, has taken observations in various exceptionally deep wells in Pennsylvania, West Virginia, Oklahoma, and Texas, with very accurate apparatus, but only a few of the data are published.

The principal feature brought out by the data here presented is the fact that the rate of increase in underground temperature with increase in depth varies widely from place to place, though probably subject to certain regional relations. There is also a local and possibly a general variation in rate at different depths, but few of the observations have afforded data on this matter. The fact that there are regional variations has been recognized for half a century and was brought out in considerable detail in Prestwich's compilation of data

up to 1886[1] and his later publication in 1895.[2] This observer and others later have grouped earth temperatures and attempted to show their relation to rocks and minerals of various kinds,[3] petroleum,[4] flowing water, etc. There are undoubtedly in the earth many factors that may influence the rate of temperature increase, such as variation in conductivity of rocks, underground tension, mineralization, volcanic influences, and movement of underground waters. Variation in radioactivity has been suggested as a factor, and the influence of bodies of cold water, such as Lake Superior, and the former presence of glacial ice are thought to be causes of local diminution of earth temperature. Positive evidence is lacking as to all these matters, however, and we must await the results of extended special investigations before the weight of the several factors can be evaluated.

In nearly all my calculations of the rate of increase in temperature with increase in depth mean annual air temperatures were used as a standard. These were obtained from publications of the Weather Bureau, United States Department of Agriculture, and nearly all of them represented averages up to and including 1916.[5] In places for which no observations are on record temperatures were deduced from means of near-by stations, with due consideration of difference in latitude and altitude. It is realized that these means of air temperature may differ from the ground temperature a few yards below the surface to the amount of 2° or more, but they were the only data available for comparison.[6] In a few places the temperatures at shallow depths were recorded, and the rate of increase could also be calculated from them.

The thermometers used by me and my assistants and supplied to certain correspondents were maximum self-registering instruments made to order by Henry Green, of Brooklyn, N. Y. The style is similar to that used by William Hallock, but certain modifications were found desirable. The modified form has been termed the Darton thermometer, but the difference hardly merits the title. The main features are shown in figure 1. A 10-inch outer tube of heavy glass, sealed, carries an 8-inch thermometer held by plugs of cork, C; S, stricture; r, rounded end of mercury column. The calibra-

[1] Prestwich, J., On underground temperatures: Roy. Soc. London Proc., vol. 41, pp. 1–116, 1886.

[2] Prestwich, J., On underground temperatures, in Collected papers on some controverted question in geology, pp. 166–279, published separately, London, 1895.

[3] Königsberger, J., Normale und anormale Werte der geothermischen Tiefenstufe: Centralbl. Mineralogie, 1907, pp. 673–679.

[4] Königsberger, J., and Mühlberg, Max, Uber Messungen der geothermischen Tiefenstufe deren Technik und Verwertung zur geologischen Prognose [etc.]: Neues Jahrb., Beilage Band 31, pp. 107–157, 1911.

[5] Climatological data for the United States by sections, vol. 3, No. 13, Washington, 1917.

[6] Slichter found while investigating the underflow of Arkansas River in western Kansas in 1904 that the temperature of water in shallow wells ranged from 56° to 58° F., or 2° to 4° higher than the mean annual air temperature of the region. (See U. S. Geol. Survey Water-Supply Paper 153, p. 12, 1906.)

tion is in degrees Fahrenheit and is readable to half a degree with certainty.

Most of the instruments were verified at the Bureau of Standards. As a rule they were used singly, but in certain places two instruments were used either simultaneously or in succession. They are intended to be sunk bulb end up, for the mercury in the bulb end does not easily jar past the stricture. In warm weather care is taken to chill the instrument before lowering. It is wrapped in flannel, placed in a 14-inch piece of 1-inch lead pipe, and usually lowered by means of No. 18 wire, with care to avoid jars.

Generally the instrument was left down the hole overnight or at least four hours. In observing temperatures of flowing water I and my assistants used ordinary 6-inch thermometers readable to half degrees and tested as to accuracy. Nothing is known as to the kind of instruments used for most of the observations given in published reports or furnished by correspondents. They probably varied in character.

Throughout this report temperatures are given in degrees Fahrenheit, depths in feet, and yield of wells in gallons a minute. Although the geothermal gradient should strictly be stated in units of temperature per unit of depth, it is customary, in order to get larger and more readily comparable quantities, to use the reciprocal statement, units of depth per unit of temperature. The figures are here given in feet per degree Fahrenheit. A high gradient is of course represented by a small number of feet per degree, and vice versa.

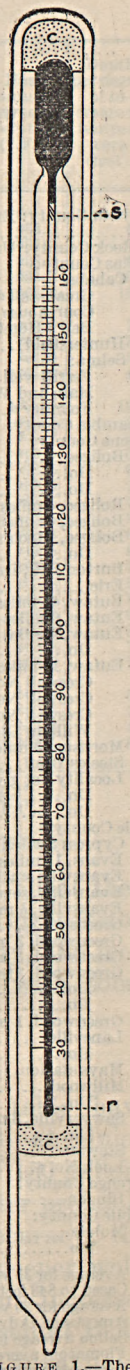

FIGURE 1.—Thermometer used in taking deep-well temperatures.

ALABAMA.

TEMPERATURE OBSERVATIONS.

Many observations of the temperature of waters from flowing and other wells in Alabama have been recorded, most of them by the State geologist.[1] Unfortunately, in the greater part of these observations the source of the water is not stated, and there is uncertainty as to the accuracy of the thermometers used. The following selected data are believed to be of sufficient value to be considered.

[1] Smith, E. A., U. S. Geol. Survey Water-Supply Paper 102, pp. 277-331, 1904.

Temperatures in wells in Alabama.

Well.	Total depth (feet).	Depth of flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).
Barbour County: Eufaula, 1 mile south of	350	.....	6	68	[a] 64.6	103
Bullock County: Union Springs	843	[b] 843	Pumps 140	76	[c] 64.6	74
Dallas County:						
Cahaba:						
Great well [d]	728	.....	1,200	77½	[e] 64.8	57
Courthouse [d]	555	.....	Many.	75	[e] 64.8	55
Bell's Hotel [d]	400	.....	Many.	73¾	[e] 64.8	45
Huntersfield	550	.....	70	69	[e] 64.8	131
Selma:						
Ferrill well [d]	487	.....	110	68	[e] 64.8	152
Main and Water streets [d]	470	.....	Many.	72	[e] 64.8	65
Foundry [d]	409	.....	230	67¾	[e] 64.8	136
Escambia County: Brewton	151–190	.....	5	68	[f] 66.1	.....
Greene County:						
Boligee	500	300 (first).	40	70	[g] 63.7	80
Do	415	.....	.....	68	[g] 63.7	96
Do	250	.....	2	68	[g] 63.7	58
Boligee, 4 miles north of	142	.....	.....	66	[g] 63.7	62
Boligee, Canfield's [d]	522	.....	.....	70	[g] 63.7	83
Boligee, Finch's Ferry [d]	550	.....	.....	71	[g] 63.7	75
Do	320	290	10	67	[h] 63.8	90
Burton Hill, Dr. Perrins	544	.....	.....	70	[h] 63.8	87
Erie	330	300	4½	68	[h] 63.8	80
Eutaw, 4½ miles south of	200	.....	2	71	[i] 63.5	27
Eutaw, 6 miles south of	340	300	10	70	[i] 63.5	46
Eutaw, 9 miles south of	495	.....	2	71	[i] 63.5	66
Do	450	.....	1	71	[i] 63.5	60
Eutaw, 10 miles south of—						
Creswell No. 1	456	.....	.....	72½	[i] 63.5	50
Creswell No. 2	440	.....	.....	71	[i] 63.5	59
Creswell No. 3	550	.....	.....	72½	[i] 63.5	61
William Glover's [d]	495	.....	.....	72½	[i] 63.5	57
Morrison, 3 miles southwest of	330	270	4½	68	[j] 63.6	66
Steeles Bluff	400	360	22	69	[j] 63.6	74
Locality not given [k]	415	.....	.....	68	[j] 63.6	66
Do	525	.....	.....	70	[j] 63.6	82
Do	544	.....	.....	72	[j] 63.6	63
Hale County:						
Cypress Switch	320	300	1½	67	[l] 63.5	86
Evans, 1¼ miles west of	210	160	24	67	[m] 63.8	50
Evansville station	200	180	30	68	[m] 63.8	43
Evansville, several near	160–200	160	3½–18	68	[m] 63.8	38
Evansville, ½ mile west of	160	140	18	67	[m] 63.8	42
Greensboro	200	140	18	68	[n] 64	35
Greenwood, 3 miles east of	200	160	65	67	61.8	32
Greenwood, 3 miles southwest of	140	140	40	67	61.8	27
Greenwood, 3 to 5 miles southwest of	160	140	17	68	61.8	23
Do	185	175	12	68	61.8	28
Do	272	175, 240	18	68	.....	.....
Greenwood, 1 mile east of	210	170	18	67	61.8	77
Laneville	710	.....	Many.	75	[o] 65	71
Do	719	.....	22	75	[o] 65	72
Mays station, 1½ miles south of	285	.....	Many.	69	[p] 61.8	40
Millwood	236	.....	850	72	[q] 64	29
Do	360	300	6	70	[q] 64	50
Sawyerville, 3 miles west of	440	440	17	70	[q] 64	73
Do	360	.....	4	69	[q] 64	72
Stewart	363	300	2	67	[r] 63.8	94
Lock No. 4	280	200	35	66	61.8	50
Marengo County:						
Linden	1,200	1,115	Pumps 20	[s] 73	[t] 65.2	143
Mobile County:						
Mobile	700	.....	400	76	[u] 66.1	71
Do	800	.....	1,000	78	[u] 66.1	67

[a] Average for 33 years.
[b] Cased to 843 feet.
[c] Average for 30 years.
[d] Am. Assoc. Adv. Sci. Proc., vol. 10, p. 95, 1856.
[e] Selma average for 27 years.
[f] Flomatom average for 25 years.
[g] Livingston average minus 0.1°.
[h] Livingston average for 33 years.
[i] Livingston average minus 0.3°.
[j] Livingston average minus 0.2°.
[k] Tuomey, Michael, Geology of South Carolina, p. 247, 1848.
[l] Mean of Greensboro and Tuscaloosa.
[m] Greensboro average minus 0.2°.
[n] Average for 38 years.
[o] Uniontown average for 31 years.
[p] Average at Lock No. 4 for 20 years.
[q] Greensboro average.
[r] Greensboro average minus 0.2°.
[s] Probably cooled by mingling of upper flows.
[t] Uniontown average plus 0.2°.
[u] Average for 45 years.

Temperatures in wells in Alabama—Continued.

Well.	Total depth (feet).	Depth of flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).
Pickens County:						
Sherman, 2 miles west of	602	.....	30	72	a63.3	69
Sherman, 1 mile south of	600	.....	6½	72	a63.3	69
Sherman, 3 miles west of	725	.....	.....	71	a63.3	94
Vienna, near	380	.....	3	67	b63.3	103
Do	350	.....	3	66	b63.3	130
Russell County:						
Glenville	175	.....	60	67	c64.6	73
Pittsboro	219	.....	1	72	c64.6	30
Do	185	.....	30	68	c64.6	54
Rutherford	165	.....	Several.	68	c64.6	48
Sumter County:						
Epes	750	.....	1	70	d63.7	120
Epes, 3 miles southeast of	930	800–900	28	79	d63.7	52
Epes, 3½ miles north of west of	700	700	1	72	d63.7	84
Gainesville, near	630	630	5	73	e63.5	66
Gainesville, 1¾ miles west of	700	.....	2	74	e63.5	67
Gainesville, 2½ miles southeast of	600	.....	3	72	e63.5	70½
Gainesville, 4 miles southeast of	550	.....	4	71	e63.5	73
Gainesville, 3½ miles south of	660	600	12	71	e63.5	80
Gainesville, 6 miles north of	500	450–500	1	71	f63.4	60
Gainesville, 4 miles southwest of	700	700	1	71	e63.5	93
Warsaw	560	560	5½	71	g63.8	78
Do	400	.....	1	68	g63.8	95
Warsaw, ½ mile west of	460	460	1	70	g63.8	74
Warsaw, 7 miles southwest of	702	702	2	71	g63.5	97
Warsaw, 1 mile west of	300	.....	⅜	69	g63.8	58
Warsaw, near	300	.....	1½	68	g63.8	71
Do	396	.....	⅜	69	g63.8	76
Tuscaloosa County:						
Hull station	210	210	38	67	b63.3	57
Hull station, 1 mile southwest of	200	200	30	66	b63.3	74
Lock No. 5	160	160	60	67	b63.3	43
Tuscaloosa, 9 miles southwest of	234	.....	2½	66	h63.1	81

a Livingston average minus 0.5°.
b Tuscaloosa average plus 0.2°.
c Union Springs average.
d Livingston average minus 0.1°.
e Livingston average minus 0.3°.
f Livingston average minus 0.4°.
g Livingston average.
h Tuscaloosa average for 36 years.

Temperatures of flows from wells that derive part or all of their water from unknown depths are reported as follows: Boguechitto, Dallas County, 460 feet deep, 68°; Boligee, Green County, 468 feet, 66½°, and 420 feet, 66°; Montgomery, 550 feet, 68°, with some water from 480 feet.

SUMMARY.

Probably several of the wells represented in the table have admixtures of water from different depths. The well at Union Springs, in Bulloch County, is pumped with an output of 150 gallons a minute, and as it is cased to a depth of 843 feet its water probably indicates the underground temperature with fair accuracy; the rate of increase indicated is 1° in 74 feet. The two deeper wells at Cahaba if cased to their bottoms indicate temperature increases of 1° in 57 and 55 feet, but the record of the shallower well at Bell's Hotel, with a rate of 1° in 45 feet, in some measure invalidates the data from the others. The 409 and 487 foot wells at Selma may have mixed flows. The exceptional temperature of 72° reported for

the 470-foot well may be a mistake. The Eutaw wells show rates of increase of 1° in 27 to 66 feet. The Steeles Bluff well is cased to a depth of 360 feet. Its recorded rate of increase of 1° in 74 feet is probably reliable if the thermometer reading is correct. This rate is subject to a small plus or minus correction due to uncertainty as to the mean annual temperature. The Hale County wells of which the depths to flowing water are recorded show considerable range in rate of increase, mostly 1° in 34 to 54 feet. The wells at Mobile indicate rates of 1° in 67 and 71 feet. The temperature of the water from the Pittsboro and Millwood wells, 72°, is remarkably high for wells only 219 and 236 feet deep and indicates rates of 1° in 30 and 79 feet, respectively. These figures might be modified slightly, however, if the exact mean annual temperature were known. The same is true of the 200-foot well 4½ miles south of Eutaw, in Greene County. Hale County also shows some high rates of increase. The low rate of the 200-foot well at Linden, in Marengo County, is a notable exception in the region southwest of Tuscaloosa. The Epes 750-foot well, the Huntersfield well, and the Selma wells (except the 470-foot well) are others having lower rates than the many wells that show increases of 1° in 50 to 90 feet.

GEOLOGIC RELATIONS.

All the wells given in the list are in the southern or Coastal Plain part of the State and penetrate sands, marls, and clays of Cretaceous and Tertiary age. These strata form a succession of sheets which dip southward at a low angle and mostly thicken in that direction. They lie on a basement of older granite, schist, and other rocks, which is nearly reached by the deeper wells in the northern part of the Coastal Plain district, among them the deeper wells in Tuscaloosa County, the wells 500 to 550 feet deep in Greene County, the deeper wells in Pickens County, the 930-foot well 3 miles southeast of Epes, in Sumter County, and the 1,200-foot well at Linden, Marengo County. These wells appear to show a wide range in rate of increase of temperature, the rate in the well at Linden, the deepest well reported, being very low—1° in 143 feet, if the temperature of the flow is given correctly. The group of wells in Bullock, Russell, and Barbour counties, most of which draw from younger formations, show no special variations. The temperature recorded for the wells in Selma, which draw from the upper part of the Tuscaloosa formation, is about 68°, indicating a low rate of increase. The wells at Mobile draw from higher beds and show a rate of 1° in about 70 feet.

ARIZONA.

SOURCE OF INFORMATION.

Underground temperatures in Arizona have been determined by W. T. Lee, C. A. Fisher, and A. T. Schwennesen, of the United States Geological Survey. In 1904 Mr. Lee made for me a number of observations in wells and shafts at the Congress mine, near Phoenix, and in the Plateau region, and from 1913 to 1915 Mr. Schwennesen[1] obtained temperatures in the San Simon Valley.

PHOENIX.

Several moderately deep borings were made in Salt River Valley near Phoenix, most of them sunk to develop water supplies from the deep desert-valley fillings. In January, 1904, Mr. Lee[2] carefully determined temperatures in these holes by sinking Darton thermometers with the results set forth below. The mean annual air temperature at Phoenix for 21 years, 69.4°, is used in the calculations of gradient.

Temperature in wells near Phoenix, Ariz.

Well.	Depth (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Murphy & McQueen ranch	349	78.1	40	Well 1,305 feet deep but clogged at 349 feet.
	150	77.6	18	
Consolidated Canal Co	375	84.6	25	Well 705 feet deep but clogged at 375 feet.
	150	81.1	13	
Sec. 30, T. 2 N., R. 4 E.	835	83	61	All water cased off; thermometer down 20 hours.
	800	82.1	63	Thermometer down 2 hours.
	700	81.9	56	Do.
	600	81.1	51	Do.
	500	80.6	45	Thermometer down 17 hours.
	400	80	38	Thermometer down 7 hours.
	300	79.8	29	Thermometer down 16 hours.
	200	79.1	21	Thermometer down 3 hours.
E. F. Kellner, sec. 6, T. 1 N., R. 1 E.	324	82.3	25	
Valley Grape Co., sec. 4, T. 1 S., R. 4 E.	319	74.4	64	

The increase is 3½° from 150 to 375 feet in the well of the Consolidated Canal Co., though it is only half a degree from 150 to 349 feet in the well at the Murphy & McQueen ranch. Lee suggests that this difference may be due to freer circulation of the underflow at the latter place.

[1] Schwennesen, A. T., Ground water in San Simon Valley, Ariz. and N. Mex.: U. S. Geol. Survey Water-Supply Paper 425, pp. 1-35, 1917.

[2] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, 1905.

CONGRESS MINE.

The large Congress gold mine, south of Prescott, Ariz., which has been worked to a depth of 1,300 feet, was selected for a series of careful determinations of temperature. The tests were made in March, 1904, by W. T. Lee, in shafts No. 6 and No. 3, which had not been worked for several months. A week in advance of the tests holes from 5 to 9 feet deep were drilled at various depths into the walls of side drifts 30 to 142 feet from these shafts but out of the main currents of ventilation. The thermometers were lightly covered and allowed to remain in the holes from 10 to 24 hours. The shafts are steep inclines, No. 6 being at an angle of about 45° and No. 3 at about 21°, and as they extend downward the land above rises considerably. The depths given below are taken from a surface profile in which the elevations were determined barometrically by Mr. Lee.

Temperatures in shafts at Congress mine, near Prescott, Ariz.

	Vertical depth (feet).	Thermometer remained in hole (hours).	Temperature (°F.).	Depth per degree of increase in temperature (feet).[a]
Shaft No. 3	205	23	68.1	.....
Do	687	10½	71.4	186
Do	1,125	10½	74.6	167
Do	1,285	22½	82.1	89
Shaft No. 6	560	24	76.6	63
Do	1,158	24	84.2	70

[a] Based on mean annual temperature of 67.7°, the average for 1897 to 1904 at the mine. This is probably too high, as the mean at Wickenburg, about 1,000 feet lower in altitude, was 64.2° for 1916.

The rate of increase in shaft No. 6 is 1° in 78.7 feet between 560 and 1,158 feet. The rates in shaft No. 3 are 1° in 146 feet between 205 and 687 feet, 1° in 137 feet between 687 and 1,125 feet, 1° in 141 feet between 205 and 1,125 feet, and 1° in 21.3 feet between 1,125 and 1,285 feet. The rock is granite, mostly massive, but at the 1,285-foot level in shaft No. 3 the observation was made 8 feet below a 2-foot zone of crushed schistose material with slickensided surfaces indicating much movement. Probably this condition caused the much greater increase of temperature between 1,125 and 1,285 feet than in the intervals above and in shaft No. 6. Shaft No. 6 is all in massive granite down to the vein, which is cut at 1,158 feet. The temperature at 1,285 feet in shaft No. 3 was verified by a duplicate observation.

PLATEAU REGION.

Several observations were made in borings along the Atchison, Topeka & Santa Fe Railway in Paleozoic rocks in the Plateau region of north-central Arizona, resulting as follows:

Temperatures in wells along Atchison, Topeka & Santa Fe Railway in north-central Arizona.

Well.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Yucca	1,004	[a]90.5	[b]67	45	Standing water below 346 feet. Test by W. T. Lee, September, 1903.
	455	80.6	67	34	No work for 3 months. Test by W. T. Lee, September, 1903.
Nelson	1,043	73.4	[c]52.3	50	553 feet of water in well. Test by W. T. Lee, September, 1903.
	200	61.2	52.3	23	No work for 4 months. Test by W. T. Lee, September, 1903.
Seligman	700	84.2	52.3	22	Thermometer down 2 hours. Well was being drilled all day and had been "shot" 8 hours before. Test by C. A. Fisher, June, 1902.
	1,216	77.9	52.3	47.5	Dry hole; tools in bottom (1,479 feet). No work for 24 hours. Test by W. T. Lee, September, 1903.
Do	227	69.5	52.3	13	Old hole. Test by C. A. Fisher, June, 1902.

[a] Duplicate tests, closely accordant.
[b] Mean of Needles, Calif., and Kingman, Ariz.; may be somewhat lower or higher.
[c] Seligman average for 10 years.

In the Yucca well the rate of increase was 1° in 55.5 feet between 455 and 1,004 feet, and in the Nelson well it was 1° in 69.1 feet between 200 and 1,043 feet. Both holes are in nearly horizontal limestone of Carboniferous age and perhaps had reached the underlying Cambrian shale. The Seligman well was tested at two levels, first at 700 feet and 14 months later at 1,216 feet, where the temperature was 6.3° cooler. At Seligman there is a mass of later Quaternary basalt several hundred feet thick which may retain some of its original heat and so cause the higher rate of increase near the surface. In another hole at this place 227 feet deep and entirely in the basalt the rate is still higher. Below the basalt the boring was in Carboniferous limestone in a shallow syncline.

SAN SIMON VALLEY.

San Simon Valley, in the southeast corner of Arizona, contains many flowing wells 200 to 1,230 feet deep, drawing their supply from the thick valley fill of sand and clay. Mr. Schwennesen made the following tests.

Temperatures in wells in San Simon Valley, Ariz.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Depth per degree of increase in temperature (feet).[a]	Remarks.
T. 13 S., R. 29 E.:					
NW. ¼ sec. 18	860	.....	83	48.6	
NE. ¼ sec. 24	960	26	105	24.2	
T. 13 S., R. 30 E.:					
NW. ¼ sec. 3	860	10	109	19.7	Two tests.
NE. ¼ sec. 9	900	8	93, 98	27.6–32.5	Do.
NW. ¼ sec. 11	950	4	96	30.9	
NE. ¼ sec. 13	760	11	88	33.4	
SW. ¼ sec. 18	900	.....	67	.....	Very small flow.
NW. ¼ sec. 23	900	9	92	33.7	
NE. ¼ sec. 24	860	3	80	58.5	
NE. ¼ sec. 25	880	1	75	90.7	
NE. ¼ sec. 25	880	14	80	59.9	
NE. ¼ sec. 25	900	9	84	48.1	
NE. ¼ sec. 25	935	1	84	50.0	
NW. ¼ sec. 26	860	1	78	67.7	
NW. ¼ sec. 30	930	10	105	23.4	Two tests.
SW. ¼ sec. 17	840	2	79	61.3	
NE. ¼ sec. 18	610	3	83	34.4	
SW. ¼ sec. 19	840	12	82	50.3	
NW. ¼ sec. 20	560	24	84	30.0	
NE. ¼ sec. 20	590	64	83	33.3	
SW. ¼ sec. 20	660	1	73	85.7	
SE. ¼ sec. 20	640	24	84	34.2	
SE. ¼ sec. 20	615	111	83	34.8	
SE. ¼ sec. 21	550	58	80	37.4	
SE. ¼ sec. 21	600	12	72	90.0	
NW. ¼ sec. 28	673	164	82	40.3	
NE. ¼ sec. 28	549	51	82, 80	37.3–32.3	Do.
NE. ¼ sec. 28	625	107	81	40.0	
NE. ¼ sec. 29	618	54	79, 78	48.7–45.1	Do.
T. 13 S., R. 31 E.:					
SW. ¼ sec. 29	760	95	81	48.4	
SW. ¼ sec. 30	1,008	5	79	73.6	
SW. ¼ sec. 31	884	36	84	47.3	
SE. ¼ sec. 31	850	36	82	51.0	
SE. ¼ sec. 33	590	200	80	40.0	
SE. ¼ sec. 33	690	21	81	44.0	
SE. ¼ sec. 33	663	170	81	42.0	
T. 14 S., R. 30 E.:					
SW. ¼ sec. 1	920	2	81	58.6	
NE. ¼ sec. 12	1,040	45	82	62.3	
NE. ¼ sec. 12	880	1	78	69.3	
SE. ¼ sec. 13	743	.....	72	111.0	
T. 14 S., R. 31 E.:					
NW. ¼ sec. 3	626	95	80	42.6	
SW. ¼ sec. 3	704	166	75	72.6	
SW. ¼ sec. 4	570	48	76	53.2	
SW. ¼ sec. 5	770	19	78	60.6	
NW. ¼ sec. 6	900	2	78	70.8	
SW. ¼ sec. 7	760	45	77	65.0	
NE. ¼ sec. 8	796	8	78	62.7	
SW. ¼ sec. 9	800	46	80	54.4	
SE. ¼ sec. 9	775	107	76	73.1	
NE. ¼ sec. 10	603	222	80	41.0	
NW. ¼ sec. 10	624	24	74	71.7	
SE. ¼ sec. 10	650	260	78	51.2	
SW. ¼ sec. 11	433	28	76	40.4	
SW. ¼ sec. 11	730	1	72	109.0	
SW. ¼ sec. 13	490	.....	80	33.3	
SW. ¼ sec. 13	530	3	76	49.5	
NW. ¼ sec. 14	440	60	75	44.4	
NW. ¼ sec. 15	822	206	79	60.0	
NW. ¼ sec. 15	790	274	80	53.7	
SW. ¼ sec. 15	726	125	83	41.0	
SE. ¼ sec. 16	715	31	79	52.2	
NE. ¼ sec. 17	830	18	84	45.4	
NW. ¼ sec. 19	1,140	1	70	242.5	
NE. ¼ sec. 21	875	.....	77	74.9	
NE. ¼ sec. 21	730	.....	84	39.0	
SE. ¼ sec. 21	800	34	85	40.7	
NE. ¼ sec. 22	620	28	78	48.8	
SW. ¼ sec. 22	750	40	85	38.1	
SE. ¼ sec. 22	770	120	83	43.5	
NW. ¼ sec. 23	705	250	84	32.3	
SW. ¼ sec. 23	750	.....	83	42.4	

[a] Calculated from 65.3°, the average at San Simon for 9 years to 1907.

Temperatures in wells in San Simon Valley, Ariz.—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
T. 14 S., R. 31 E.:—Continued.					
SE. ¼ sec. 23	620	180	80	42.2	
SE. ¼ sec. 23	720	.....	80	49.0	
SE. ¼ sec. 23	580	90	79	42.3	
NW. ¼ sec. 24	590	87	77	50.5	
NE. ¼ sec. 25	640	134	80	43.5	
SE. ¼ sec. 25	660	137	83	37.3	
NW. ¼ sec. 26	735	22	81	46.7	
NW. ¼ sec. 26	920	25	84	49.2	
NW. ¼ sec. 27	740	3	83	41.8	
T. 14 S., R. 32 E.:					
NW. ¼ sec. 19	390	20	75	40.1	
SW. ¼ sec. 19	441	300	80	30.0	
SW. ¼ sec. 19	207	254	73	26.9	
SW. ¼ sec. 29	350	34	70	74.5	
NW. ¼ sec. 31	430	20	78	33.8	
T. 15 S., R. 32 E.:					
NW. ¼ sec. 5	603	.....	76	56.3	

ARKANSAS.

TEMPERATURES.

Very few temperature determinations from Arkansas are available The following are taken mostly from a report by Veatch:[1]

Temperatures in wells in Arkansas.

Well.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Allbrook	466	.....	65	*a* 64	.....	Water pumped 1 foot.
Arkansas City	552	66	72	*b* 64	70	Pumped 550 feet.
Fordyce	502	59	72½	*c* 63	48+	Water from 460 to 502 feet.
Gurdon	760	Flow.	70	*d* 62.5	30	Water from 200 to 225 feet.
Hot Springs	860	.....	65	*e* 62.1	.....	Pumped.
Monticello	750 (or 604?)	110	79	*f* 63.2	35+	Water pumped 555 feet.
Pine Bluff	890	650	64	*g* 63	.....	Pumped.
Stamps	415	600	66	*h* 64	207+	Pumped from 233 to 345 feet.
Texarkana	937	.....	67	*i* 64.4	360	
Wilmar	194	.....	65.3	*f* 63.2	88	Water pumped from 184 to 194 feet.
Do	455	380	71.8	63.2	46½+	Water pumped from 400 to 455 feet.
White Cliff Chalk Co	450	.....	64	.....	.....	
Do	540	.....	65	.....	.....	

a Centerpoint average for 16 years.
b Greenville, Miss., average minus 0.1°.
c Camden average for 30 years minus 0.3°.
d Amity average for 24 years.
e Average for 24 years.
f Warren average for 34 years.
g Average for 32 years.
h Camden average plus 0.7°.
i Average for 21 years.

[1] Veatch, A. C., Geology and underground-water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 153–177, 1906.

SUMMARY.

The data for Allbrook, Hot Springs, Pine Bluff, Stamps, and Texarkana apparently are not valid, probably because the true source of the flow is not given. The temperatures in other wells appear to be consistent. These wells are in the southern quarter of the State and reach water-bearing strata in the great Tertiary sedimentary series of the Mississippi embayment.

GEOLOGIC RELATIONS.

The Gurdon well draws from the Nacatoch sand in the Upper Cretaceous; the Arkansas City well, the shallow well at Wilmar, and the Fordyce well, all with high rates of increase in temperature, draw from Eocene beds at the horizon of the Yegua ("Cockfield") formation, about 1,500 feet higher; the Monticello well and the 455-foot well at Wilmar, both with high rates of increase, draw from coarser deposits of Eocene age not far below the Yegua horizon.

CALIFORNIA.

SOUTHERN CALIFORNIA.

W. C. Mendenhall,[1] in studying the hydrology of southern California, determined the temperature of water flowing from many artesian and other wells and from several hot springs. The following list sets forth the principal data obtained in San Bernardino Valley:

Temperatures in wells in San Bernardino Valley, Calif.

Well.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).
Riverside, Waterman Avenue	984	75	a 63	82
Mound City:				
½ mile northwest of	784	74	a 63	71
½ mile west of	656	75	a 63	55
1 mile west of	125	68	a 63	25
½ mile northwest of	582	74	a 63	53
½ mile west of	534	74	a 63	49
1 mile northeast of	517	73	a 63	52
Do	506	70	a 63	72
2 miles north by east of	472	70	a 63	67
½ mile northwest of	482	74	a 63	44
½ mile northwest of	320	73	a 63	32
2 miles northwest of	83	68	b 62.7	16
1½ miles north of	196	70	b 62.7	27
Do	190	70	b 62.7	26
Do	142	70	b 62.7	19
1¾ miles north of	148	68.5	b 62.7	25
Do	141	67	b 62.7	33
Do	181	68	b 62.7	34
2 miles north of	472	70	b 62.7	65
Urbita, new well	740	78	c 62.5	48

a Mean annual temperature for Riverside for 35 years.
b San Bernardino average for 25 years plus 0.2°.
c San Bernardino average for 25 years.

[1] Hydrology of San Bernardino Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 142, 124 pp., 1905.

Temperatures in wells in San Bernardino Valley, Calif.—Continued.

Well.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).
San Bernardino:				
Payne well, 2 miles southeast of	642	112	a 62.5	13
City well on Antell tract, 2 miles east of	614	69	a 62.5	94
1 mile east of	544	68	a 62.5	99
2 miles east of	682	68	a 62.5	129
3 miles northeast of	460	72	a 62.5	48
2 miles south of	225	71	a 62.5	27
Do	121	98	a 62.5	3
Do	158	85	a 62.5	7
2 miles north by east of	169	76	a 62.5	13
Harlem Springs:				
1 mile south of	451	90	a 62.5	17
1 mile west of	231	72	a 62.5	24
1½ miles west of	185	80	a 62.5	11
1 mile west by south of	150	68	a 62.5	27
¼ mile north of	300	115	a 62.5	6
⅜ mile northwest of	68	86	a 62.5	3
Colton:				
2 miles east of	92	73	63	9
Do	81	73	63	8
Do	68	71	63	8

a San Bernardino average for 25 years.

The distribution, depths, and geothermal gradients of most of these wells are shown in figure 2.

The data in the table present variations that are difficult to understand. Some of them are not reliable, because flows from higher horizons may have ingress to the well, and in a few wells the outflow is small, but these two conditions cause diminished temperatures. The materials penetrated by the borings are a thick series of Quaternary sand, gravel, and clay lying horizontal and constituting a wide desert plain. The conditions are favorable for rapid circulation of water, so that the mean annual air temperature 62.5° should be expected to extend some distance below the surface. On the edge of the basin and at Harlem Springs there are thermal springs, and in a local crumple of the beds passing through Bunker Hill warm waters come very near the surface. The areas of high temperature are probably due to seepage of warm spring waters along or near recent faults. Admixture with the shallow underflow causes the great diversity of temperatures shown.

The 642-foot boring 2 miles southeast of San Bernardino, whose water has a temperature of 112°, appears to have tapped a particularly warm spot, although shallower borings a short distance southwest show nearly the same rate of temperature increase. The water of the Urbita Springs has a temperature of 102° to 105°. Several wells near the Bunker Hill anticlinal ridge show temperatures of 85° to 105°, and the shallow wells of the Riverside Water Co. along the north bank of Santa Ana River show temperatures of 71° to 73°. Deeper wells, 320 to 656 feet deep, near Loma Linda show temperatures

of 70° to 75°, but the rate of increase is not so high in these wells as in the other wells just mentioned.

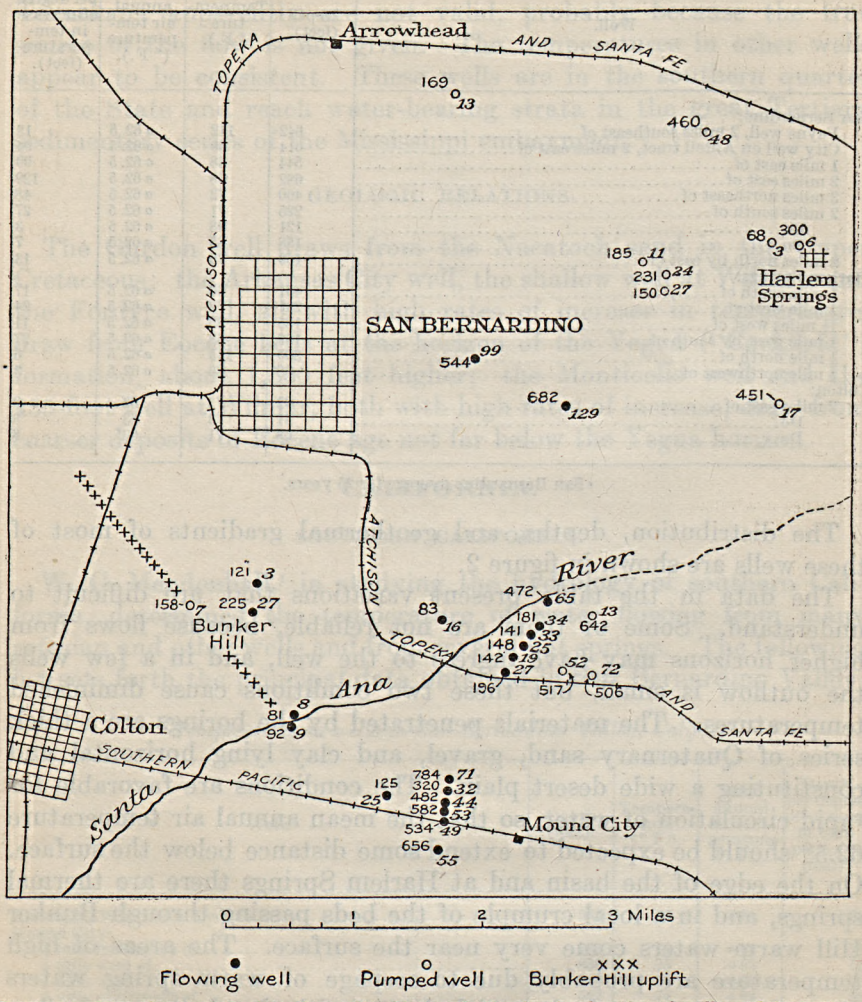

FIGURE 2.—Map of part of the San Bernardino Valley, Calif., showing location of wells and indicating geothermal gradient. Depths of wells are represented by gothic figures, and italic figures show the depth in feet per degree of increase in temperature. Data from Mendenhall's report.

Mendenhall [1] has recorded the temperatures in many wells in the Anaheim and Santa Ana districts of the eastern coastal-plain region of southern California, and, although most of them are too shallow to indicate the geothermal gradient, they present some interesting features. Most of the wells are from 80 to 200 feet deep, and the waters show unaccountable variations in temperature, mostly from 61° to 65° and a few to 70°. Of the few deeper wells covered by the

[1] Mendenhall, W. C., Development of the underground waters in the eastern coastal-plain region of southern California: U. S. Geol. Survey Water-Supply Paper 137, 1905.

records one flowing well 397 feet deep in the San Joaquin district showed a temperature of 79°, which indicates a rate of increase of about 1° in 23 feet. Another well near by, 165 feet deep, with a temperature of 81°, indicates a still higher rate. The temperature of water from a 386-foot well was 67°, a 390-foot well 70°, a 264-foot well 71°, a 360-foot well 71°, a 336-foot well 71°, a 400-foot well 68°, two 450-foot wells 66°, and a 118-foot well 71°. Some of the wells showing the higher temperatures are in groups or districts, but others appear to be irregularly distributed.

Temperatures in the Cucamonga and Pasadena region have been recorded by Mendenhall, as follows:

Temperatures in wells in Cucamonga and Pasadena quadrangles, Calif.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).
Cucamonga quadrangle: [a]					
Cucamonga	541	.....	71	[b] 62.5	64
Do	479	280	72	62.5	50
Do	456	56	72	62.5	49
Do	433	33	72	62.5	46
Do	428	45	73	62.5	41
Do	666	.....	64	62.5	.....
Do	638	850	62	62.5	.....
Do	624	850	62	62.5	.....
Do	640	850	62	62.5	.....
Do	540	850	62	62.5	.....
Do	649	1,675	70	62.5	144
Santa Ana del Chino	375	.....	64	62.5	250
Do	126	.....	67	62.5	30
Do	300	.....	69	62.5	46
Do	374	900	66	62.5	107
Do	347	225	65	62.5	140
San Jose	400	500	62	62.5	.....
Sec. 33, T. 1 N., R. 8 W	385	340	64	62.5	.....
Do	367	280	70	62.5	49
Pasadena quadrangle:					
Los Angeles	307	.....	68	[c] 60.3	40
Do	283	.....	66	60.3	50
Do	276–280	.....	68	60.3	36
Sec. 9, T. 2 S., R. 13 W	210	.....	65	60.3	45
San Antonio	205–226	.....	60	60.3	.....
Do	189	.....	62	60.3	110
Do	175	.....	68	60.3	23
Do	202	165	61	60.3	.....
San Pasqual	160	335	65	[d] 62.5	64
Do	492	280	65	62.5	197
Do	140	560	67	62.5	33
Do	130	22	71	62.5	18
Santa Anita	156	45	71	62.5	15
Sec. 20, T. 1 S., R. 11 W	302	670	68	62.5	55
San Francisquito	130	1,750	64	62.5	87

[a] Mendenhall, W. C., Ground waters and irrigation enterprises in the foothill belt, southern California: U. S. Geol. Survey Water-Supply Paper 219, pp. 140–174, 1908.
[b] Azusa average for 15 years.
[c] Average for 40 years.
[d] Pasadena average for 27 years.

In this region other wells from 113 to 300 feet deep show temperatures of 62°; wells 68 and 172 feet deep, 63°; 280 feet, 64°; 250 feet, 65°; 60 and 160 feet, 66°; 147, 160, and 300 feet, 67°; 139, 160, 180, 250, and 255 feet, 68°; and 140 and 220 feet, 69°. These figures indicate great irregularity in the rate of increase at slight depths.

SAN LUIS OBISPO.

A flow of sulphur water from a 928-foot well at San Luis Obispo has a temperature of 103°. As the mean annual air temperature at this place is 57.2°, this indicates a rate of increase of 1° in 20 feet.

SAN JOAQUIN VALLEY.

Mendenhall and Dole [1] have given records of many observations of temperatures of wells in San Joaquin Valley. Most of the wells are shallow, but others are deep and flowing, so that their temperatures throw much light on the rate of increase. These wells are all in the filling of loam, clay, sand, and gravel, occupying a broad valley between mountain ranges of older rocks. These deposits are known to be more than 2,000 feet thick in places. It is believed that none of the wells here recorded have reached their base. The data which appear to be most useful are given in the following list:

Temperatures in wells in San Joaquin Valley, Calif.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).
Fresno County:					
Sec. 22, T. 13 S., R. 14 E.	700	70	78	[a] 63.2	47
Sec. 31, T. 13 S., R. 15 E.	640	80	78	63.2	43
Sec. 2, T. 14 S., R. 15 E.	750	225	78	63.2	50½
Sec. 10, T. 14 S., R. 16 E.	800	180	78	63.2	54
Sec. 12, T. 15 S., R. 16 E.	800	112	77	63.2	58
Sec. 25, T. 15 S., R. 16 E.	825	.....	76	63.2	64½
Sec. 19, T. 15 S., R. 16 E.	700	22	79	63.2	44
Sec. 11, T. 15 S., R. 15 E.	733	125	76	63.2	57
Sec. 25, T. 15 S., R. 17 E.	750	345	80	63.2	44½
Sec. 14, T. 16 S., R. 17 E.	690	90	75	63.2	58½
Sec. 2, T. 17 S., R. 18 E.	1,200	.....	78	63.2	81
Sec. 17, T. 17 S., R. 19 E.	700	190	77	63.2	50½
Sec. 21, T. 17 S., R. 19 E.	1,500	260	82	63.2	79½
Sec. 28, T. 17 S., R. 19 E.	1,200	168	80	63.2	71½
Sec. 1, T. 17 S., R. 20 E.	700	11	80	63.2	41½
Sec. 36, T. 18 S., R. 16 E.	1,178	80	80	63.2	70
Sec. 5, T. 19 S., R. 20 E.	500	35	76	63.2	39
Sec. 28, T. 18 S., R. 20 E.	700	225	76	63.2	54½
Kern County:					
Sec. 20, T. 25 S., R. 24 E.	800	2,900	78	[b] 62.2	50½
Sec. 26, T. 25 S., R. 24 E.	995	45	82	62.2	50
Sec. 34, T. 25 S., R. 24 E.	647	230	78	62.2	41
Sec. 3, T. 26 S., R. 24 E.	500	.....	80	62.2	28
Sec. 11, T. 26 S., R. 24 E.	1,000	.....	82	62.2	50½
Sec. 31, T. 25 S., R. 25 E.	700	155	79	62.2	41
Sec. 17, T. 26 S., R. 24 E.	512	345	79	62.2	30½
Sec. 19, T. 26 S., R. 24 E.	480	580	78	62.2	30½
Sec. 34, T. 26 S., R. 23 E.	369	620	78	62.2	23½
Sec. 32, T. 26 S., R. 23 E.	284	1,330	78	62.2	18
Sec. 34, T. 26 S., R. 22 E.	320	975	76	62.2	23
Sec. 6, T. 27 S., R. 23 E.	800	650	82	62.2	40½
Sec. 10, T. 27 S., R. 23 E.	423	70	76	62.2	55
Sec. 3, T. 27 S., R. 25 E.	700	.....	78	62.2	44
Sec. 5, T. 28 S., R. 23 E.	+600	1,160	76	62.2	40½
Sec. 24, T. 28 S., R. 23 E.	390	515	76	62.2	28
Sec. 25, T. 28 S., R. 23 E.	450	335	73	62.2	41½

[a] Fresno average for 30 years.
[b] Wasco mean annual average for 17 years.

[1] Mendenhall, W. C., Dole, R. B., and Stabler, Herman, Ground water in San Joaquin Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 398, pp. 185–298, 1916.

Temperatures in wells in San Joaquin Valley, Calif.—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).
Kern County—Continued.					
Sec. 18, T. 29 S., R. 23 E.	600	.....	67	62.2	125
Sec. 30, T. 29 S., R. 24 E.	800	.....	67	62.2	167
Sec. 5, T. 29 S., R. 29 E.	1,300	22	87	[a] 65.1	59
Sec. 5, T. 29 S., R. 29 E.	400	340	92	65.1	15
Sec. 4, T. 30 S., R. 27 E.	450	550	68	65.1	155
Sec. 26, T. 30 S., R. 26 E.	950	22	72	65.1	137½
Sec. 34, T. 30 S., R. 26 E.	+500	34	69	65.1	128
Sec. 12, T. 31 S., R. 26 E.	560	45	70	65.1	114
Sec. 12, T. 31 S., R. 26 E.	500	250	74	65.1	56
Sec. 7, T. 31 S., R. 28 E.	400	45	67	65.1	.....
Sec. 20, T. 31 S., R. 27 E.	650	.....	76	65.1	59½
Sec. 19, T. 31 S., R. 27 E.	1,395	22	72	65.1	202
Sec. 32, T. 31 S., R. 26 E.	415	200	78	65.1	33
Sec. 6, T. 32 S., R. 26 E.	416	200	79	65.1	30
Sec. 2, T. 31 S., R. 27 E.	345	180	78	65.1	26½
Sec. 30, T 31 S., R. 27 E.	645	260	74	65.1	72½
Sec. 30, T. 31 S., R. 27 E.	645	200	78	65.1	50
Sec. 4, T. 32 S., R. 27 E.	582	45	74	65.1	65½
Sec. 9, T. 32 S., R. 27 E.	507	22	74	65.1	57
Sec. 8, T. 32 S., R. 27 E.	378	33	74	65.1	42½
Sec. 16, T. 32 S., R. 27 E.	648	80	74	65.1	72½
Sec. 21, T. 32 S., R. 27 E.	896	33	75	65.1	90½
Kings County:					
Sec. 21, T. 19 S., R. 20 E.	400	Few.	77	[b] 62.2	27
Sec. 36, T. 20 S., R. 21 E.	700	370	73	62.2	65
Sec. 36, T. 20 S., R. 21 E.	400	11	73	62.2	37
Sec. 1, T. 21 S., R. 21 E.	1,100	380	76	62.2	80
Sec. 1, T. 21 S., R. 21 E.	1,600	400	78	62.2	101
Sec. 10, T. 20 S., R. 20 E.	820	335	77	62.2	55
Sec. 6, T. 21 S., R. 22 E.	450	.....	74	62.2	38
Sec. 21, T. 21 S., R. 22 E.	1,225	245	74	62.2	104
Sec. 21, T. 21 S., R. 22 E.	1,200	370	74	62.2	102
Sec. 21, T. 21 S., R. 22 E.	1,247	480	72	62.2	127
Sec. 21, T. 21 S., R. 22 E.	1,106	.....	72	62.2	113
Sec. 14, T. 21 S., R. 22 E.	928	335	71	62.2	105
Sec. 15, T. 22 S., R. 22 E.	950	270	72	62.2	97
Sec. 24, T. 22 S., R. 22 E.	1,200	145	78	62.2	76
Sec. 25, T. 22 S., R. 22 E.	1,540	680	85	62.2	67
Sec. 25, T. 22 S., R. 22 E.	308	Few.	71	62.2	34
Merced County:					
Sec. 27, T. 6 S., R. 9 E.	300	45	72	[c] 63.2	35
Sec. 26, T. 6 S., R. 9 E.	300	35	72	63.2	35
Sec. 22, T. 7 S., R. 11 E.	250	100	72	63.2	28½
Sec. 21, T. 7 S., R. 11 E.	338	80	73	63.1	34½
Sec. 33, T. 7 S., R. 11 E.	328	100	73	63.2	33½
Sec. 11, T. 7 S., R. 10 E.	250	22	74	63.2	23
Sec. 7, T. 7 S., R. 10 E.	330	70	74	63.2	30½
Sec. 9, T. 8 S., R. 9 E.	580	.....	77	63.2	42½
Sec. 9, T. 9 S., R. 9 E.	430	Few.	77	63.2	31
Sec. 13, T. 9 S., R. 9 E.	402	.....	78	63.2	27
Sec. 36, T. 9 S., R. 10 E.	750	225	79	63.2	47½
Sec. 21, T. 11 S., R. 12 E.	550	Few.	76	63.2	43
Sec. 3, T. 8 S., R. 13 E.	685	35	76	63.2	53½
Sec. 16, T. 8 S., R. 13 E.	707	80	75	63.2	60
Sec. 26, T. 8 S., R. 13 E.	750	.....	74	63.2	69½
Sec. 27, T. 8 S., R. 14 E.	325	11	74	63.2	30
Sec. 4, T. 9 S., R. 13 E.	698	13	73	63.2	71
Sec. 21, T. 9 S., R. 13 E.	400	50	74	63.2	37
San Joaquin County:					
Stockton Gas & Electric Co.	1,800	60	97	[d] 60.1	49
Do.	1,498	170	89	60.1	52
Do.	2,500	.....	101	60.1	61
Stockton Insane Hospital.	1,990	.....	91	60.1	64
Do.	1,750	115	88	60.1	63
Stockton Citizens Gas Co.	2,078	1,450	96	60.1	58
Do.	1,786	1,450	94	60.1	53
Stockton Crown Mills.	1,210	125	90	60.1	41
Stockton old well.	[e] 1,080	Many.	75	60.1	72
Stockton county well.	1,003	.....	77	60.1	60
Stockton Glass Co.	2,100	168	88	60.1	75
Stockton Jackson Wells.	1,850	560	85	60.1	68
Do.	1,700		85	60.1	74

[a] Bakersfield average for 28 years; wells 27 to 109 feet, 68° to 71° mostly.
[b] Hanford average for 17 years.
[c] Merced average for 43 years.
[d] Stockton average for 46 years.
[e] Well cased to bottom; flows also at 980 and 1,030 feet, which may mingle.

Temperatures in wells in San Joaquin Valley, Calif.—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).
San Joaquin County—Continued.					
Campo de los Franceses	1,045	Few.	79	60.1	55
Do	1,128	22	84	60.1	47
Sec. 10, T. 2 N., R. 6 E	1,165	100	84	60.1	46
Sec. 22, T. 1 S., R. 6 E	1,400	.....	84	60.1	59
Sec. 8, T. 1 S., R. 1 E	1,250	.....	77	60.1	74
Sec. 25, T. 1 S., R. 6 E	1,200	90	74	60.1	86
Tulare County:					
Sec. 30, T. 18 S., R. 24 E	800	11	78	[a] 61.6	48
Sec. 29, T. 19 S., R. 24 E	420	90	75	61.6	31
Sec. 31, T. 19 S., R. 24 E	430	60	76	61.6	30
Sec. 7, T. 20 S., R. 24 E	470	.....	74	[b] 63.2	43½
Sec. 16, T. 20 S., R. 24 E	462	.....	74	63.2	43
Sec. 10, T. 20 S., R. 23 E	505	70	74	63.2	46½
Sec. 11, T. 20 S., R. 23 E	1,150	230	75	63.2	97½
Sec. 5, T. 20 S., R. 24 E	430	270	73	63.2	44
Sec. 32, T. 20 S., R. 24 E	1,000	11	72	61.3	114
Sec. 30, T. 20 S., R. 24 E	500	45	75	63.2	42
Sec. 25, T. 20 S., R. 23 E	640	45	74	63.2	60
Sec. 25, T. 20 S., R. 23 E	787	270	76	63.2	61
Sec. 35, T. 20 S., R. 23 E	600	540	74	63.2	55½
Sec. 22, T. 20 S., R. 23 E	418	56	73	63.2	43
Sec. 28, T. 20 S., R. 23 E	521	80	74	63.2	48
Sec. 32, T. 20 S., R. 24 E	530	56	74	63.2	49
Sec. 32, T. 20 S., R. 23 E	800	325	75	63.2	68
Sec. 32, T. 20 S., R. 23 E	868	270	76	63.2	68
Sec. 8, T. 21 S., R. 23 E	954	450	78	[c] 64.8	72
Sec. 3, T. 21 S., R. 23 E	900	475	75	64.8	88
Sec. 3, T. 21 S., R. 23 E	750	270	74	64.8	81½
Sec. 10, T. 21 S., R. 23 E	800	225	74	64.8	87
Sec. 10, T. 21 S., R. 23 E	778	425	75	64.8	72
Sec. 26, T. 21 S., R. 24 E	600	22	72	64.8	83
Sec. 4, T. 22 S., R. 24 E	600	134	72	64.8	83
Sec. 23, T. 21 S., R. 24 E	500	56	70	64.8	96
Sec. 28, T. 21 S., R. 24 E	400	80	72	64.8	55½
Sec. 29, T. 21 S., R. 24 E	500	100	72	64.8	70
Sec. 31, T. 21 S., R. 24 E	630	56	71	64.8	101½
Sec. 17, T. 22 S., R. 23 E	815	340	76	64.8	73
Sec. 17, T. 22 S., R. 23 E	918	875	78	64.8	69½
Sec. 21, T. 22 S., R. 23 E	800	560	78	64.8	60½
Sec. 30, T. 22 S., R. 23 E	1,000	850	81	64.8	61½
Sec. 30, T. 22 S., R. 23 E	1,200	340	77	64.8	98½
Sec. 29, T. 22 S., R. 23 E	700	.....	68	64.8	218½
Sec. 29, T. 22 S., R. 23 E	830	Few.	76	64.8	74
Sec. 8, T. 22 S., R. 24 E	606	180	70	64.8	116½
Sec. 20, T. 22 S., R. 24 E	606	270	70	64.8	116½
Sec. 10, T. 22 S., R. 24 E	435	.....	69	64.8	104
Sec. 10, T. 22 S., R. 24 E	480	150	69	64.8	114
Sec. 22, T. 22 S., R. 24 E	600	180	70	64.8	115
Sec. 22, T. 22 S., R. 24 E	1,400	56	71	64.8	226
Sec. 22, T. 22 S., R. 24 E	450	35	69	64.8	107
Sec. 24, T. 22 S., R. 24 E	500	200	70	64.8	96
Sec. 23, T. 22 S., R. 24 E	1,100	400	70	64.8	211
Sec. 13, T. 22 S., R. 24 E	1,043	35	72	64.8	145
Sec. 3, T. 23 S., R. 25 E	680	.....	76	64.8	61
Sec. 7, T. 23 S., R. 25 E	500	90	78	64.8	38
Sec. 7, T. 23 S., R. 25 E	800	35	77	64.8	65
Sec. 8, T. 23 S., R. 25 E	1,387	450	79	64.8	98
Sec. 18, T. 23 S., R. 25 E	500	35	76	64.8	45
Sec. 11, T. 23 S., R. 24 E	1,142	.....	80	64.8	75
Sec. 11, T. 23 S., R. 24 E	815	.....	70	64.8	157
Sec. 11, T. 23 S., R. 24 E	1,000	.....	78	64.8	76
Sec. 35, T. 22 S., R. 24 E	900	125	70	64.8	173
Sec. 34, T. 22 S., R. 24 E	582	205	75	64.8	57
Sec. 3, T. 23 S., R. 24 E	600	360	74	64.8	65
Sec. 9, T. 23 S., R. 24 E	1,000	850	18	64.8	76
Sec. 16, T. 23 S., R. 24 E	1,100	2,300	80	64.8	72
Sec. 3, T. 23 S., R. 23 E	1,103	465	78	64.8	83½
Sec. 3, T. 23 S., R. 23 E	1,025	215	78	64.8	77½
Sec. 33, T. 23 S., R. 25 E	1,300	245	75	64.8	127½

[a] Visalia average for 30 years.
[b] Mean of Visalia and Porterville.
[c] Porterville average for 28 years.

The water in many shallow wells in San Joaquin Valley has temperatures ranging from 65° to 72°, or considerably higher than the mean air temperature.

INDIO BASIN.

Mendenhall [1] has given the temperatures of flow from many of the artesian wells in the Indio Basin. They all draw from gravel and sand in the deep Quaternary valley fill, the bottom of which has not been reached by any of the borings.

Temperatures in wells in Indio Basin, Calif.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).
Sec. 23, T. 6 S., R. 8 E.	499	135	74
Sec. 23, T. 6 S., R. 8 E.	509	260	74
Sec. 23, T. 6 S., R. 8 E.	497	225	74
Sec. 23, T. 6 S., R. 8 E.	512	225+	76
Sec. 23, T. 6 S., R. 8 E.	526	58	74
Sec. 25, T. 6 S., R. 8 E.	538	.....	74
Sec. 26, T. 6 S., R. 8 E.	487	170	74
Sec. 26, T. 6 S., R. 8 E.	514	170	74
Sec. 26, T. 6 S., R. 8 E.	601	90	74
Sec. 23, T. 6 S., R. 8 E.	519	170	74
Sec. 22, T. 6 S., R. 8 E.	506	.....	74
Sec. 22, T. 6 S., R. 8 E.	498	280	74
Sec. 16, T. 7 S., R. 9 E.	484	225	76
Sec. 18, T. 7 S., R. 9 E.	525	.....	76
Sec. 8, T. 7 S., R. 9 E.	547	125	77
Sec. 8, T. 7 S., R. 9 E.	531	150	77
Sec. 12, T. 5 S., R. 7 E.	165	.....	74
Sec. 23, T. 5 S., R. 7 E.	465	22	73
Sec. 13, T. 5 S., R. 7 E.	600+	.....	78
Sec. 13, T. 5 S., R. 7 E.	480	.....	78
Sec. 23, T. 5 S., R. 7 E.	652	45	74
Sec. 34, T. 6 S., R. 8 E.	510	415	73
Sec. 34, T. 6 S., R. 8 E.	487	383	73
Sec. 16, T. 7 S., R. 8 E.	400	280	81
Sec. 18, T. 7 S., R. 9 E.	380	70	74
Sec. 12, T. 7 S., R. 8 E.	409	157	76
Sec. 12, T. 7 S., R. 8 E.	480	280	74
Sec. 17, T. 6 S., R. 8 E.	558	80	74
Sec. 17, T. 6 S., R. 8 E.	500	336	72
Sec. 20, T. 6 S., R. 8 E.	518	112	73
Sec. 20, T. 6 S., R. 8 E.	500	68	73
Sec. 20, T. 6 S., R. 8 E.	520	180	74
Sec. 30, T. 6 S., R. 8 E.	407	80	74
Sec. 30, T. 6 S., R. 8 E.	437	90	74
Sec. 30, T. 6 S., R. 8 E.	474	257	74
Sec. 30, T. 6 S., R. 8 E.	430	.....	74
Sec. 30, T. 6 S., R. 8 E.	446	22	74
Sec. 30, T. 6 S., R. 8 E.	410	125	74
Sec. 24, T. 6 S., R. 7 E.	480	45	74
Sec. 14, T. 6 S., R. 7 E.	577	.....	72
Sec. 20, T. 7 S., R. 9 E.	480	415	76
Sec. 20, T. 7 S., R. 9 E.	640	370	76
Sec. 20, T. 7 S., R. 9 E.	565	335	75
Sec. 8, T. 7 S., R. 9 E.	550	347	76
Sec. 8, T. 7 S., R. 9 E.	563	34	77
Sec. 12, T. 7 S., R. 8 E.	464	390	74
Sec. 2, T. 7 S., R. 8 E.	496	.....	74
Sec. 2, T. 7 S., R. 8 E.	495	.....	74
Sec. 2, T. 7 S., R. 8 E.	499	526	74
Sec. 2, T. 7 S., R. 8 E.	477	291	74
Sec. 2, T. 7 S., R. 8 E.	550	.....	74
Sec. 35, T. 6 S., R. 8 E.	584	145	74
Sec. 35, T. 6 S., R. 8 E.	497	335	74
Sec. 35, T. 6 S., R. 8 E.	495	291	74
Sec. 35, T. 6 S., R. 8 E.	504	620	74
Sec. 35, T. 6 S., R. 8 E.	515	370	75
Sec. 34, T. 7 S., R. 8 E.	780	.....	90
Sec. 5, T. 6 S., R. 8 E.	549	168	73

[1] Mendenhall, W. C., Ground waters of the Indio region, Calif., with a sketch of the Colorado Desert: U. S. Geol. Survey Water-Supply Paper 225, 1909.

Temperatures in wells in Indio Basin, Calif.—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).
Sec. 5, T. 6 S., R. 8 E.	548	45	73
Sec. 6, T. 6 S., R. 8 E.	557	22	73
Sec. 6, T. 6 S., R. 8 E.	586	200	70
Sec. 5, T. 6 S., R. 8 E.	550	.....	73
Sec. 5, T. 6 S., R. 8 E.	553	.....	73
Sec. 5, T. 6 S., R. 8 E.	540	180	73
Sec. 5, T. 6 S., R. 8 E.	548	.....	73
Sec. 5, T. 6 S., R. 8 E.	558	340	73
	547		73
Sec. 5, T. 6 S., R. 8 E.	545	450	73
Sec. 8, T. 6 S., R. 8 E.	563		73
Sec. 8, T. 6 S., R. 8 E.	541	45	73
Sec. 5, T. 6 S., R. 8 E.	510	225	73
Sec. 8, T. 6 S., R. 8 E.	500	.....	72
Sec. 12, T. 6 S., R. 7 E.	500	130	72
Sec. 12, T. 6 S., R. 7 E.	329	145	74
Sec. 26, T. 6 S., R. 7 E.	320	112	74
Sec. 26, T. 6 S., R. 7 E.	335	100	74
Sec. 25, T. 6 S., R. 7 E.	340	100	74
Sec. 36, T. 6 S., R. 7 E.	385	170	74
Sec. 1, T. 7 S., R. 7 E.	397	170	73
Sec. 32, T. 6 S., R. 8 E.	400	235	73
Sec. 32, T. 6 S., R. 8 E.	540	190	74
Sec. 32, T. 6 S., R. 8 E.	484	358	74
Sec. 32, T. 6 S., R. 8 E.	448	257	74
Sec. 32, T. 6 S., R. 8 E.	438	70	74
Sec. 4, T. 7 S., R. 8 E.	474	80	74
Sec. 4, T. 7 S., R. 8 E.	440	258	74
Sec. 22, T. 6 S., R. 8 E.	498	90	74
Sec. 22, T. 6 S., R. 8 E.	375	157	74
Sec. 22, T. 6 S., R. 8 E.	580	280	74
Sec. 26, T. 6 S., R. 8 E.	572	180	74
Sec. 26, T. 6 S., R. 8 E.	510	210	74
Sec. 26, T. 6 S., R. 8 E.	500	125	74
Sec. 26, T. 6 S., R. 8 E.	511	100	74
Sec. 35, T. 6 S., R. 8 E.	509	292	74
Sec. 35, T. 6 S., R. 8 E.	500	215	74
Sec. 22, T. 6 S., R. 8 E.	577	225	74
Sec. 4, T. 6 S., R. 8 E.	542	130	75
Sec. 5, T. 6 S., R. 8 E.	574	130	74
Sec. 10, T. 6 S., R. 8 E.	526	90	75
Sec. 10, T. 6 S., R. 8 E.	532	112	75
Sec. 10, T. 6 S., R. 8 E.	517	90	75
Sec. 34, T. 7 S., R. 8 E.	220	390	91
Sec. 34, T. 7 S., R. 8 E.	250	390	91
Sec. 14, T. 8 S., R. 8 E.	300	33	92
Sec. 24, T. 8 S., R. 8 E.	315	390	94
Sec. 24, T. 8 S., R. 8 E.	315	640	90
Sec. 12, T. 7 S., R. 8 E.	464	.....	70

The flows from most of these wells have remarkably low temperatures. Some are only a degree or two warmer than the mean annual air temperature of 73.9° (the average for 39 years at Indio), and several are colder. One well 400 feet deep in sec. 16, T. 7 S., R. 8 E., has water 8° warmer than that found in closely adjoining wells of similar depth. The 780-foot well in sec. 34 has a flow with a temperature of 90°, indicating a rate of increase of 1° in 48 feet, and two wells near by 220 and 250 feet deep have flows with a temperature of 91°, indicating rates of increase of 1° in 13 and 15 feet, respectively. About 3 and 4 miles to the south, along a prolongation of the same line, are wells yielding large flows with temperatures of 92°, 94°, and 90°. It is probable that these wells tap a supply from a fissure, possibly a fault, along which heated waters are rising from a deep-seated source. It is stated that a 500-foot hole was sunk in

the bottom of the Salton Basin before the inundation and obtained a flow of water with a temperature of 92°.

OIL REGION.

In investigating the chemistry of the waters of the oil fields in San Joaquin Valley Rogers [1] determined temperatures of flow from several deep wells in Fresno and Kern counties.

Temperatures in several deep wells in Fresno and Kern counties, Calif.

Location.	Depth of source of flow (feet).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Fresno County:					
Sec. 12, T. 21 S., R. 14 E..	2,077	118	[a] 61.5	37	Sulphur water 600 feet below oil sand.
Sec. 2, T. 20 S., R. 14 E..	1,104	86	61.5	45	
Kern County:					
Sec. 9, T. 31 S., R. 22 E..	3,860	131	[b] 65	58½	Flow probably from 3,000+ feet below main oil sand.
Sec. 32, T. 12 N., R. 23 E.	2,505	115	65	50	Flow from below oil sand, about 100 feet above second oil sand.
Sec. 35, T. 31 S., R. 22 E..	1,495–1,727	120	65	27+	About 100 feet below lowest oil sand.
Sec. 15, T. 32 S., R. 23 E..	1,765–1,820	102	65	48	Flow from about 150 feet below oil sand.
Sec. 25, T. 32 S., R. 23 E..	1,460	97	65	46	Flow from about 50 feet below oil sand.
Sec. 31, T. 32 S., R. 24 E..	1,334–1,609	109	65	30+	Do.
Sec. 26, T. 12 N., R. 24 W.	2,540–2,560	93	65	91	Flow from about 125 feet below oil sand.
Sec. 12, T. 11 N., R. 24 W.	3,550	104	65	91	Flow from about 2,550 feet below oil sand.
Sec. 35, T. 32 S., R. 23 E..	1,090	84	65	58	Shale of Monterey group.
Sec. 28, T. 31 S., R. 23 E..	3,000	125	65	50	Flow from a few feet below oil sand.

[a] Hanford average minus 7° for difference in altitude.
[b] Bakersfield average minus 1°.

It is reported that in a 5,390-foot hole at Rosemary station the oil at 3,000 feet had a temperature of 140° to 160°.

GRASS VALLEY.

Lindgren [2] made observations of temperatures in the mines of gold-bearing quartz in the Grass Valley and Nevada City districts in 1894. Thermometers were left in holes with the following results: 30 feet below surface, 53½°; 1,513 feet below surface, 66°; 1,513 feet below surface (dry hole in quartz), 67¼°; 1,553 feet below surface, 66°. These observations indicate a rate of increase of 1° in 122 feet at 1,553 feet and of 1° in 105 feet at 1,513 feet.

[1] Rogers, G. S., Chemical relations of the oil-field waters in San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 653, 1917.

[2] Lindgren, Waldemar, The gold quartz veins of Nevada City and Grass Valley districts, Calif.: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 170–171, 1896.

COLORADO.

ARKANSAS VALLEY.

There are flowing wells at short intervals along the valley of Arkansas River from Canon City to Granada, Colo. The temperatures in some of them are as follows:

Temperatures in wells in Arkansas Valley, Colo.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Canon City:						
Oil company, sec. 23[a]	1,600	700	90	[b] 52.9	31	Flow probably from 1,150 feet.
Sanitarium 3 miles northeast, sec. 26.	1,670	Many.	98½	52.9	36	Water from 1,650 feet, test by owner.
Florence:						
Sec. 14	800	1,000	86	52.9	35	Test by N. H. Darton.
10 miles southeast of	1,085	750	92	52.9	28	Test January, 1905, by Dick Rule with Darton thermometer.
SW. ¼ sec. 26, T. 18 S., R. 69 W.[c]	1,230	360	87	52.9	36	
Pueblo:						
Grand Hotel	1,219	20	76	[b] 51.5	49½	Pressure 50 pounds. Test by N. H. Darton Nov. 7, 1898.
Sec. 12, T. 21 S., R. 65 W.	1,260	25	80½	51.5	43	Pressure 15 pounds.
Ferris Hotel	1,400	½	77.2	51.5	54½	Pressure 61 pounds. Test by N. H. Darton Nov. 7, 1898.
Clarks	1,402	87	79.5	51.5	50	Flow through 8 feet of rubber hose. Test by N. H. Darton Nov. 7, 1898.
South of	1,464	100	82	51.5	39	Flow at 1,180 feet.
Baxter, 4½ miles north of	660	.....	73.2	51.5	30½	Test by C. A. Fisher February, 1904. Down 3 hours, water stands at 550 feet. Some gas.
Boone, 2½ miles north of	1,000	49	82.5	51.5	32	Test by C. A. Fisher, February, 1904; down 3 hours. Dry hole.
Manzanola	1,113	42	80	[d] 51.5	39	Large flow.
Rocky Ford	767	130	78	51.5	29	Do.
Rocky Ford, sec. 18	790	68	74	51.5	35	Do.
Rocky Ford	793	68	78	51.5	30	Do.
Do	820	38	75	51.5	35	Do.
Rocky Ford, Wychoff Park	845	115	72	51.5	41	Do.
Do	1,003	17	75	51.5	43	Do.
La Junta	412	8	68	[e] 52	26	Do.
La Junta mill	420	45	70	52	23	Do.
La Junta, railroad	420	.....	68	52	26	Air pumped.
Do	439	.....	68	52	27½	Do.
Do	700	.....	68	52	44	Water probably from higher level, at least in part.
La Junta	640	35	68	52	40	
La Junta Home Co	766	25	68	52	48	Do.
La Junta, near	740	12	75	52	32	Do.

[a] 51st Cong., 1st sess., S. Ex. Doc. 222, p. 214.
[b] Canon City average for 29 years.
[c] Fuller, M. L., and Sanford, Samuel, Record of deep-well drilling for 1905: U. S. Geol. Survey Bull. 298, p. 193. Water from 1,210 to 1,223 feet; cased to 1,040 feet.
[d] Average for 28 years.
[e] Rocky Ford average plus 0.50.°

SAN LUIS VALLEY.

Siebenthal [1] has supplied many observations of well temperatures in the San Luis Valley. The following data are compiled from his report:

Temperatures in wells in or near Alamosa, Colo.

Location.	Depth (feet).	Depth of flow (feet).	Flow (gallons per minute).	Temperature (° F.).[a]	Depth per degree of increase in temperature. (feet).[b]	Remarks.
Northeast corner sec. 10	1,000	932	600	74.7	20	Smaller flow at 500 feet may mingle.
Northwest corner sec. 10	865	.....	400	72	30	Cased to 852 feet.
Goodall well	883	876	Many.	70	32	Small flow at 261, 507, and 617 feet; larger ones at 776 and 883 feet.
North of Alamosa	725	.....	Few.	66	.....	Probably a higher flow mingles.
Mill	680	680	Many.	69	26	Cased to bottom.
Electric-light plant	800+	800+	Many.	73	40±	Do.
1½ miles south of Alamosa	810	810	350	72	28	Do.
1 mile southeast of Alamosa	800	800	Many.	72	28	Do.
4 miles north of Alamosa	840	840	130	72	29	Do.
Near Fountain	585	.....	Many.	64	28	
La Jara	308	.....	Many.	48	62	
Do	325	.....	Many.	49½	50	Cased to 300 feet.
Los Sauces, near	200–300	.....	25	53–55	20–25	
Lockett, near	805	800	150	63	40	
Veteran, near	265	265	250	54	24	Cased to bottom.
Do	383	335	Many.	55	28	
Swede Corners	156	147	Many.	61	8	
Do	220	.....	.....	58½	14	
Swede Corners, 1½ miles northeast of.	189	189	.....	58	12	
Swede Corners, 1½ miles northeast of.	126	.....	.....	45	83	
Moffat, near	640	616	.....	61	34	
Do	300	300	8	51	37	
San Isabel, near	380	.....	55	55½	30	
Do	375	.....	58	58	25	
Baca grant	481	.....	10	62	25	
Mosca	500	.....	50	66	22	
Do	600	.....	.....	69	23	
Do	385	.....	.....	60	23	Second flow.
Do	500	500	.....	63	25	Separate casing.
Do	.....	340	.....	62	18	Do.
Do	800	.....	90	71	29	
Mosca, 5 miles west of	712	.....	120	63	36	
Hooper	740	740	70	69	28	Cased to bottom.
Do	300	300	1	53	30	Do.
Hooper, near	425	.....	Many.	54	39	
Do	550	.....	.....	59	34	Flow from above 380 feet.
Do	630	.....	70	60	36	Cased to 360 feet.
Kinney ranch	766	.....	.....	68	51	Considerable gas.
Jacobs ranch	500	.....	25	58	33	Cased to 125 feet.
Do	404	.....	.....	57	29	Cased to 224 feet.
San Luis	22–32	.....	.....	45–47	.....	
Del Norte	450	450	2	54	41	

[a] Temperature about Alamosa observed by Prof. Carpenter.
[b] Based on an approximate mean annual of 43° averaged from observations in adjoining regions.

It is suggested that the high rate about Swedes Corners is probably due to the presence of an old lava flow, a part of which crops out 1 mile west and 3 miles north from the Corners.

[1] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, pp. 57–98, 1910.

The flow from a 405-foot well on Cotton Creek, in Saguache County, is reported to have a temperature of 58°, but as the mean annual air temperature at that locality is not known the rate of increase can not be calculated.

LEADVILLE.

It is reported [1] that a 400-foot well in sec. 25 near Leadville yields a flow with a temperature of 58°. As the mean annual air temperature at Leadville is 35° (average for 18 years) this would indicate a rate of increase of about 1° in 17 feet.

TRINIDAD.

In June, 1905, W. T. Lee made temperature determinations at various depths in a 2,500-foot boring at Trinidad. The hole was found to be plugged at 770 feet, and a Darton thermometer left at that depth for several hours recorded 69.6°. A test at 370 feet gave 67.8°. As the mean annual temperature of Trinidad is 51.3° (average for 15 years) these readings indicate rates of increase of 1° in 42 feet and 22 feet, respectively. The difference between the two readings, however, indicates a rate of increase of 1° in 222 feet between depths of 370 and 770 feet.

DENVER BASIN.

Few data are available as to the temperatures in many wells in the vicinity of Denver that formerly flowed. The following figures [2] may possibly be significant:

Temperatures in wells in and near Denver, Colo.

Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Depth per degree of increase of temperature (feet).[a]	Remarks.
350	¼	56	56	
340	3	58	41	Some flow from 240 feet perhaps.
407	30	62	33	
239	Many.	55	46	
445	50	62	.....	
410	.....	58	50	Same well.
563	20	66	35	
635	10	62	52	Littleton.
352	140	[b] 52	160	Cased to 248 feet.
620	325	[b] 65	38	Principal flows from 250 and 575 feet. Both same temperature.
480	300	[b] 57	67	Cased to 350 feet.

[a] Calculated from mean annual temperature of 49.8°, average for 45 years.
[b] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, pp. 456–459, 1896.

[1] Fifty-first Cong., 1st sess., S. Ex. Doc. 222, p. 329.
[2] Idem, pp. 188–208, 334, 336, 337.

MISCELLANEOUS LOCALITIES.

Temperatures of wells in Montrose, Akron, and Loveland, Colo.

Locality.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Montrose	[c] 829	72	[b] 47.3	33½	Flow tested by N. H. Darton Nov. 5, 1898.
Akron	670	64	[c] 49	45	Thermometer sunk by C. A. Fisher, 1898; in well 3½ hours.
Loveland	2,465	58	[d] 46.7	[e] 121	Flow stated to be from 1,365 feet; tested by C. A. Fisher, 1898.

[a] 30-gallon flow.
[b] Average for 21 years.
[c] Approximated from Fort Morgan, 48.7° (20-year average).
[d] Fort Collins average for 33 years.
[e] Calculated to 1,365 feet.

SUMMARY.

The rate of increase of temperature in wells in the Arkansas Valley varies considerably, but in most of them it is high. From Baxter to La Junta the average is near 1° in 34 feet and variations from the average are mostly less than 10 feet. The Pueblo wells show an average near 1° in 50 feet, but farther west the rate is higher. In San Luis Valley the rate is 1° in 33 to 42 feet so far as the few observations show. The Trinidad hole showed too much variation to be significant. The rate in the Denver wells was 1° in 33 to 56 feet, at Montrose 1° in 33½ feet, and at Akron 1° in 45 feet. The observation at the Loveland well is open to question as to the source of the flow.

GEOLOGIC RELATIONS.

Wells in the Arkansas Valley below the Pueblo draw from the Dakota and associated sandstones, which dip gently eastward. The well in T. 18 S., R. 69 W., also reaches the Dakota sandstone. The Florence wells penetrate much higher sandstones in a basin holding coal measures, and the Canon City holes are on the west rise of this basin. The San Luis Valley wells are in Quaternary valley filling. The Trinidad hole was in the Pierre shale at 770 feet. Wells in the Denver Basin penetrate the nearly horizontal younger Tertiary deposits. At Montrose the Dakota sandstone was probably reached, and the Akron hole was in the Pierre shale. The precise relations at the Leadville well are not known, but the region contains limestone cut by igneous rocks and greatly mineralized.

FLORIDA.

Although many determinations of temperature of flows from artesian wells in Florida have been published, there are few reliable data to indicate the geothermal gradient. This is due largely to lack of information as to the depth from which the water is derived and as to whether or not higher flows mingle with the main flow.

ST. AUGUSTINE.

In the large well at the Ponce de Leon Hotel, St. Augustine, the main flow, from 1,340 to 1,390 feet, has a temperature of 86°.[1] As the mean annual temperature of St. Augustine is 69.5° (65-year average), this would indicate a rate of increase of 1° in 81.2 feet, providing no water enters the casing above 1,340 feet. When the well was being bored the temperatures of water from the principal large flows brought rapidly to the surface in the sand pump from various depths were recorded as follows:[2]

Temperature at different depths in well at Ponce de Leon Hotel, St. Augustine, Fla.

Depth (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).
170	74	38
410	76	63
520	79	55
1,110	80	106
1,225	85	79
1,340–1,390	86	81

The temperature at a depth of 35 feet was reported as 62°, or 7½° less than the mean annual air temperature. The rate of increase from 170 to 1,340 feet is 1° in 87½ feet.

[1] Am. Jour. Sci., 3d ser., vol. 34, p. 70, 1887.
[2] Florida Geol. Survey Third Rept., pp. 114-115, 151, 1910.

MISCELLANEOUS DATA.

Data for Florida, some of which may be reliable, are as follows:

Temperatures in wells in Florida.

Location.	Depth (feet).	Flow (gals.).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Brevard County:						
Eau Gallie	230	.....	78	[a] 72.6	43	Large flow; well 325 feet.
Malabar	350	.....	78	72.6	65	Large flow; first flow at 280 feet, probably mingles.
Melbourne, 1 mile west of.	400?	.....	77	72.6	90	Large flow; possibly some from 318 feet.
Micco	500?	.....	78	72.6	93	Large flow; may be from 250 feet.
Rockledge	350	.....	80	[b] 72	44	Large flow; cased to bottom.
Titusville	218	.....	75	[c] 71.2	60	Large flow.
Clay County:						
Greencove Springs	500	.....	80	[d] 68.3	42½	300-gallon flow; well 815 feet.
Magnolia Springs	362	.....	74	68.3	64	Large flow.
Orange Park	450	.....	78	68.3	46½	Do.
Duval County:						
Mandarin	550	.....	77	[e] 68.2	62½	"Flow from 550 feet."
Jacksonville Electric Co.	1,020	.....	81	68.2	.....	Main flow probably from 555 feet; another at 975 feet.
Jacksonville city well	984	.....	77½	68.2	.....	Water probably also from 524, 750, and 860 feet.
Do	498	.....	71	68.2	.....	Mixed flows.
Do	635	.....	74	68.2	.....	
Do	.....	.....	.....	68.2	.....	
Do	900	.....	74	68.2	.....	Do.
Do	1,031	.....	74	58.2	.....	Do.
Jacksonville, 3 miles east of	800	.....	75	68.2	118	Flow from bottom.
Lee County:						
Fort Myers	496	.....	80	[f] 73.1	72	Cased to bottom. Large flow.
Fort Myers 1 mile east of.	403	.....	80	73.1	56	150-gallon flow.
Manatee County:						
Braidentown	347	Many.	72	[g] 71.7	.....	Flow from 347 feet.
Ellentown	400	Many.	80	[g] 71.7	48	Flow mostly from 200 feet.
Manatee	368	150	74	[g] 71.7	150	Flow from 348 feet.
Terra Ceia	378	Many.	75	[h] 71.9	116	Flow from 360 feet.
Do	350	250	76	[h] 71.9	73	Flow from 300 feet.
Marion County: Ocala	1,210	Many.	74½	[i] 70.2	284	Pumped 74 feet.
Nassau County: Fernandina	700	810	74	[e] 68.2	121	
Osceola County: Kissimmee	309	Many.	75	[i] 72.3	52	Water from 140 feet.
Putnam County:						
Crescent City	300	Many.	72	[j] 69.6	125	Water from 300 feet.
Federal Point	160–250	200–600	72–75	[i] 69.6	.....	Water from 155 to 200 feet.
Do	250	500	72	[i] 69.6	83	Water from 200 feet.
Do	225	600	75	[i] 69.6	31	Water from 168 feet.
Palatka	206	Many.	76	[k] 69.9	31	Water from 190 feet.
Do	250	Many.	72	[k] 69.9	119	Water from 250 feet.
San Mateo	280	Many.	78	[l] 70	35	Water from 280 feet.
St. Lucie County:						
Orchid	368	Many.	78	[m] 72.6	66	
Orchid, ¼ mile east of	400	Many.	78	[m] 72.6	74	
Sebastian	460	Many.	75	[n] 72.7	200	
Do	350	Many.	75	[n] 72.7	152	
St. John County:						
Hastings	155	120	75	[o] 69.6	29	Water from 155 feet.
Switzerland	337	400	72	[p] 68.9	107	Water from 330 feet.
Do	300	400	72	[p] 68.9	90	Water from 280 feet.
Volusia County:						
Many wells	100–163	Many.	70–73	[q] 70	.....	
Ormond	230	Many.	70	70	.....	
Lake Helen	227	115	78	70	28	

[a] Malabar average for 25 years.
[b] Orlando average minus 3°.
[c] 21 years average.
[d] Middleburg average.
[e] Jacksonville average for 46 years.
[f] Average for 48 years.
[g] Average for 33 years.
[h] Braidentown average plus 2°.
[i] Average for 25 years.
[j] Average for 18 years.
[k] Federal Point average plus 0.3°.
[l] Federal Point average plus 0.4°.
[m] Fort Pierce average minus 0.3°.
[n] Fort Pierce average minus 0.2°.
[o] St. Augustine average plus 0.1°.
[p] St. Augustine average minus 0.6°.
[q] Deland average for 20 years.

SUMMARY.

Apparently the most important data on temperature here presented are those from St. Augustine, Fort Myer, Mandarin, and Rockledge. Some of the others may be reliable, but there is a possibility that in many of the wells higher flows mingle with the main flow. The source of the flows at Melbourne and Micco is not known, and most of the other wells in Brevard County are shallow. The flows at Jacksonville are known to be mixed, for although the main flow is derived from a depth of 555 feet other flows come in, notably in the deeper wells, which tap a flow at a depth of 975 feet, below a body of clay. Temperatures of flows in the 984-foot city well, which is cased only to 494 feet, are stated [1] to be as follows: 524 to 727 feet, 76° to 77½°; 865 to 970 feet, 78° to 79°; flow at mouth, 77½°. The large flow from the 496-foot well at Fort Myer probably affords a true indication of underground temperature, although it shows a smaller rate of increase than is indicated by the well a mile east of Fort Myer.

GEOLOGIC RELATIONS.

The wells in Florida penetrate sands, clays, and limestones of Tertiary age, which lie nearly horizontal and are uniform in character over wide areas. Those at St. Augustine, Jacksonville, and Mandarin penetrate deeply into Oligocene limestones of the Vicksburg group, which are overlain by clays and sands of later Tertiary age. These limestones were also reached by the holes in Brevard and Clay counties and at Fort Myer. The variations in geothermal gradient have no obvious connection with geologic features.

GEORGIA.

TEMPERATURES.

Local observers have furnished records of the temperature of flows from several wells in Georgia which afford a few data as to the geothermal gradient. Other facts regarding the wells are given by McCallie [2] and by Stephenson and Veatch. [3]

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[1] U. S. Geol. Survey Bull. 298, p. 196, 1906.

[2] McCallie, S. W., A preliminary report on the artesian-well system of Georgia: Georgia Geol. Survey Bull. 7, 214 pp., 1898; A preliminary report on the underground waters of Georgia: Georgia Geol. Survey Bull. 15, 370 pp., 1908.

[3] Stephenson, L. W., and Veatch, J. O., Underground waters of the Coastal Plain of Georgia: U. S. Geol. Survey Water-Supply Paper 341, 539 pp., 1915.

Temperatures in wells in Georgia.

Locality.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Chatham County: Savannah, 12 miles west of.	659	Many.	72	[a] 66.6	122	
Dougherty County: [b] Albany city well.	750	200	73½	[c] 66.9	103	Cased to 660 feet, principal flow from 680 feet.
Albany, well No. 2[d]	1,320	125	78	[c] 66.9	119	Cased to bottom.
Evans County: Claxton [e]	546½	100	75	[f] 65.8	59	Cased to 459 feet, water begins at 460 feet. Water pumped to 80 feet.
Glynn County: Brunswick	465	600	70	[g] 67	155	Possibly some flow from 300 feet also.
McIntosh County: Valona	455	120	70	[h] 66.1	116	Possibly some flow from 320 to 365 feet also.
Pierce County: Offerman [e]	675½	250	76	[i] 67.2	73	Cased to 635 feet. Water 640 to 675½ feet. Rises to within 33 feet of surface.
Pulaski County: Hawkinsville	490	Many.	71	[j] 62.4	57	Cased to bottom. Flows.
Ware County: Way Cross, 2 wells.	691	Many.	72½	[k] 67.2	127	Air-pumped, main supply 670 to 691 feet.
Wilcox County: Bowens mill.	673	Many.	74	[l] 66.2	86	Source of water not given.

[a] Average for 67 years.
[b] Georgia Geol. Survey Bull. 7, pp. 178–181, 1902.
[c] Average for 30 years.
[d] Georgia Geol. Survey Bull. 15, pp. 97–99, 1908.
[e] U. S. Geol. Survey Bull. 298, pp. 201–202, 1906.
[f] Statesboro average for 17 years.
[g] Average of various distant stations.
[h] Savannah average + 0.5°.
[i] Waycross average for 28 years.
[j] Average for 11 years.
[k] Average for 28 years.
[l] Eastman average for 25 years.

SUMMARY.

The data given indicate considerable variation in the geothermal gradient in Georgia, but it is difficult to know which are reliable. The figures for the Claxton, Hawkinsville, and Offerman wells appear to be valid, and the source of flow in the wells at Albany and a well 12 miles west of Savannah, which show a low rate of increase, may be correctly reported. The Waycross water is probably cooled by air lift. The Georgia wells can not be grouped geographically by their rates of increase or by their depths.

GEOLOGIC RELATIONS.[1]

The wells in the list are all in the Coastal Plain province, in which sheets of sand, gravel, and clay of Cretaceous and Tertiary age dip gently to the east and southeast. The older beds lie on a basement of pre-Cambrian crystalline rocks, which slopes to the southeast and is far beneath the surface along the coast and at the Florida State line. The Albany deeper wells draw from the Ripley formation, high in the Cretaceous. The water-bearing stratum at Hawkinsville and Bowens Mill is sand, probably at the top of the Cretaceous or the base of the Eocene. The Offerman, Claxton, and Waycross wells draw from beds in the Eocene at a considerably higher horizon, and

[1] For details regarding relations of wells see Stephenson, L. W., and Veatch, J. O., op. cit.

the Savannah, Brunswick, and Valona wells may reach beds still higher. From these statements it will be seen that there is no apparent relation between the rates of increase in temperature and the water horizons.

IDAHO.

BOISE.

The water of the artesian wells at and near Boise is reported to have temperatures of 80° to 170°. As the depths of these wells are less than 500 feet, the higher temperatures, at least, indicate a very high geothermal gradient, which is due, doubtless, to local volcanic conditions.

SNAKE RIVER VALLEY.

Russell [1] reports temperatures in a number of wells along the Oregon Short Line Railroad on the Snake River Plains as observed by Scott Turner. They all indicate high temperatures. The most notable are as follows:

Temperature in wells along Oregon Short Line Railroad in southwestern Idaho.

Location.	Depth (feet).	Depth of flow (feet).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).
Bliss	483	430	70	[a]50.3	22
Cleft	450	.....	73	[b]48.6	19
Owyhee	600	530	70	52	30
Nampa	114	40	61½	50	.....

[a] Approximated from averages at Boise and Garnet. [b] Mountain Home average.

Russell [2] has also given data of wells on the south side of Snake River valley in Owyhee County. The temperatures are high, and as there are numerous hot springs in the region it is believed that the wells draw in part from deep-seated thermal waters rising in fissures. The wells all flow from 20 to 120 gallons a minute and are sunk to sands in the Payette formation, of lower Tertiary age.

[1] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 173, 1902.

[2] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southwestern Oregon: U. S. Geol. Survey Water-Supply Paper 78, p. 35, Washington, 1903.

Temperature in wells in Owyhee County, Idaho.

Locality.	Depth (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).
Guffey	538	76½	22
Central	1,033	100	21½
Do	940	98	20½
Do	1,035	106	19
Do	720	100	15
Enterprise	340	87	9½
Do	385	90	10
Hot Spring, 5 miles north of	700	90	18½
De Lamar [a]	975	120	14

[a] Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 104), p. 8, 1904.

These rates are based on an assumption that the mean annual temperature is 52° F., a figure approximated from observations at distant stations.

Russell also states that the water in a 240-foot well near Hot Springs, in Bruneau Valley, Owyhee County, had a temperature of 109° F. The well flows 7 gallons a minute and is near a hot spring of the same temperature. There are many shallow wells on these lava plains of Snake River which yield warm water, but as the region is one of relatively recent volcanic activity the lava flows are doubtless the source of the heat.

NEZ PERCE COUNTY.

In his report on Nez Perce County, Russell[1] gives a number of temperatures of deep wells and warm springs. A 220-foot well on the Dowd farm, 8 miles southeast of Lewiston, has a flow of 15 to 20 gallons a minute, which in December, 1900, John Adams found to have a temperature of 58¾°. A copious spring near by had a temperature of 54°. Several wells about 100 feet deep, not far away, had flows with temperatures of 66° to 68°, according to the same observer. The mean annual temperature of the locality is estimated by Russell as 48° to 49°. Russell believed that the water must come from a depth of 540 to 1,000 feet in these wells in order to account for the high rate of increase indicated, but as the region is underlain by recent basalt it appears to me more likely that this rock at a moderate depth is the source of the heat.

ILLINOIS.

TEMPERATURES.

About fifty records of temperatures in deep wells in various parts of Illinois were obtained, and although in many of the wells the flows are mixed, in others the depth of flow is known and the rate of increase is indicated. At Streator and St. John Darton thermometers were sunk to the bottom of the wells.

[1] Russell, I. C., Geology and water resources of Nez Perce County, Idaho: U. S. Geol. Survey Water-Supply Paper 54, pp. 106–109, 1901.

Temperatures in wells in Illinois.

Location.	Depth (feet).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Alexander County: Cairo:[a]					
Halliday Hotel	824	62	57.5	155	Water possibly all or mainly from 498 to 518 feet.
Halliday residence	811	62	57.5	155	60-gallon flow from 753 feet; no increase below 700 feet.
Near mouth of Cache River	806	62	57.5	163	Water from 735 feet or higher.
Cook County:					
Evanston	1,602	65	[b] 48.5	97	Source of flow not given. Probably higher waters mingle.
Oak Park	2,180	64	48.5	.....	
Chicago[c]	751	55	48.5	115	
Hancock County: Warsaw	844	60	[d] 51.4	98	Source of flow not given.
Henry County: Kewanee, 3 wells.	1,500	65	[e] 49.4	90	Cased to 1,330 feet.
Knox County:					
Galesburg[f]	1,226	60	[g] 50	[h] 106	Cased to St. Peter sandstone at 1,060 feet. Pumped 160 feet; main supply from 1,100 to 1,215 feet.
Knoxville	1,360	68	50	[i] 66	Cased to St. Peter at 1,180 feet.
La Salle County: Streator	2,496	[j] 76	[k] 50.4	97	Thermometer to bottom.
Mercer County: Aledo	3,115	68	[l] 50	.....	Cased 1,705 to 1,805 feet. "Most of flow from bottom."
McDonough County: Macomb.	1,630	68	[m] 51	[n] 67	Cased to St. Peter sandstone at 1,135 feet.
Perry County: St. John Coal & Salt Co.	3,735	[o] 101	56.3	83.5	Thermometer down 24 hours.
Putnam County: Hennepin	800	58	[p] 49.4	93	Cased nearly to bottom.
Peoria County:[q]					
Peoria Asylum	1,600	78	[l] 49.9	56.9	Source of flow not known.
Pulsifer well	900	65	.....	59.6	Do.
Stockyards	850	65	.....	56.3	Do.
Sulphur water house	800	62	.....	66.1	Do.
Rock Island County:[r]					
Carbon Cliff	950	60	[s] 49.4	90	Do.
East Moline	1,050	61.5	49.4	87	No casing.
Milan[t]	1,027	61.5	49.4	85	
Moline:					
Prospect Park	1,121	61	49.4	99	Flows may mingle.
Paper mills	1,375	63	49.4	101	Do.
Rock Island:					
Hubers Brewery	1,187	60.5	49.4	[u] 82	Cased to 912 feet.
Mitchell & Lynie	2,049	68	49.4	83	Cased to 1,200 feet. "Probably main flow from 1,550 feet."
St. Clair County: Marissa	685	65	[v] 55.2	70	Pumps 30 gallons 200 feet.
Stark County: Bradford	2,054	68	[w] 49.4	110	Cased to 1,600 feet. Water pumped 175 feet.
Tazewell County: Pekin	950	70	[x] 49.9	42	Sulphur water.
Whiteside County: Sterling	1,450	62	[y] 48.2	105	

[a] Glenn, L. C., Underground water of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U. S. Geol. Survey Water-Supply Paper 164, pp. 150–152, 1906.
[b] Chicago average for 42 years.
[c] Schott, C. A., On underground temperatures: Smithsonian Rept. for 1874, p. 250.
[d] Keokuk, Iowa, average for 46 years.
[e] Galva average for 24 years.
[f] Udden, J. A., Some deep borings in Illinois: Illinois Geol. Survey Bull. 24, p. 65, 1914.
[g] Approximated.
[h] Calculated to 1,060 feet.
[i] Calculated to 1,180 feet.
[j] Taken by Prof. R. Williams with thermometer from U. S. Weather Bureau.
[k] Average for 23 years.
[l] Average for 61 years.
[m] Approximate mean annual.
[n] Calculated to 1,135 feet.
[o] Observation by superintendent in 1899 with Darton thermometer down 24 hours. Dry hole. Limestone below 2,500 feet. Another 24-hour observation gave 95° and a short one gave 93°, all in the midst of working double shift.
[p] La Salle average to 1908.
[q] Udden, J. A., Artesian wells in Peoria and vicinity: Illinois Geol. Survey Bull. 8, p. 334, 1908.
[r] All taken by Prof. J. A. Udden, 1898, with a Sargent thermometer reading 1° higher than instruments in U. S. Weather Bureau, Davenport, Iowa.
[s] Davenport average for 45 years.
[t] Upper flow cased off, but casing may be corroded through as suggested by diminished pressure.
[u] Calculated to 912 feet.
[v] Maccoutah average for 26 years.
[w] Henry average for 28 years.
[x] Peoria average for 26 years.
[y] Dixon average for 26 years.

SUMMARY.

The most satisfactory observations of underground temperature in Illinois are those made at St. John and Streator, where thermometers were sunk to the bottoms of the holes. At St. John the instrument was left down 24 hours. When withdrawn it read 101°, indicating a rate of increase of 1° in 83.5 feet. The temperatures in wells in Rock Island County were accurately taken by Prof. Udden. The variation which some of them show is possibly due largely to mingling of flows. However, the observations were made just after vigorous drilling, and some heat of impact may be manifest. The wells at Peoria give results so closely accordant that presumably the flows are all from the bottom or near it. The Hennepin well, "cased nearly to the bottom," and the Knoxville, Chicago, Marissa, and Galesburg wells give close approximations of rate if the water is not cooled by pumping. The temperatures in the Cairo wells may not be accurately determined.

Flows from the deep well at Aledo may be mixed, and if so the rate of 1° in 168 feet is not valid. The Oak Park flow is undoubtedly mixed. The high temperature of water from the 950-foot well at Pekin probably indicates a source at the bottom of the well, and the rate of 1° in 42 feet is considerably higher than that of any other well in the State.

The rates of increase given in the list appear not to have any regional relations but vary from place to place. Galesburg and Knoxville, not far apart, apparently have rates of 1° in 106 feet and 66 feet, respectively. Pekin is not far south of Peoria, where the average rate is 1° in 60 feet.

GEOLOGIC RELATIONS.

The Illinois wells penetrate limestone, shale, and sandstone of Carboniferous to Ordovician age, all lying nearly horizontal, without local disturbances of large amount and with no volcanic rocks. The Streator well is stated to be on a low anticline trending northwestward. The deep wells in the southern part of the State reach the oldest strata, most of them drawing from the St. Peter sandstone. At Peoria the shallower wells in the Niagara limestone show no material difference in rate of increase in temperature from the deeper ones, which draw from the St. Peter sandstone. A similar condition is presented by various wells of Rock Island County. The Cairo wells penetrate Cretaceous deposits to a depth of about 500 feet and then enter flint rock and sandstone of Mississippian age. If the flows are from about 500 feet, the base of the Cretaceous, the rate is 1° in about 110 feet.

INDIANA.

TEMPERATURES.

The few well temperatures on record for Indiana are not very significant, because no statement is furnished as to the depth from which the water comes. The following data may be of interest:

Temperatures in wells in Indiana.

Location.	Depth (feet).	Temperature (feet).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Brown County: Nashville	530	56	[a] 53	176	Flows 300 gallons a minute.
Carroll County:					
Delphi, several wells	898-928	62	[a] 50.7	80	Oil wells.
Flora	1,040	62	50.7	92	Do.
Cass County: Logansport [b]	447	54	[c] 50.9	.....	
Crawford County: English	887	60	[a] 56	222	300-gallon flow.
Decatur County: Sandusky	830	60	[a] 53	118	
Lake County:					
Hammond, 2 wells	1,780	60	[d] 49	162	Water probably from shallow source or chilled by pumping.
Fort Wayne [e]	2,635	51.5	[f] 50.1	.....	
Wabash [e]	2,270	50.5	.....	.....	
Terre Haute [e]	1,923	81	[g] 54.6	73	
Laporte County: Michigan City	833	57	[h] 49	104	Flows 300 gallons a minute.

[a] From U. S. Weather Bureau map.
[b] Capps, S. R., Underground waters of north-central Indiana: U. S. Geol. Survey Water-Supply Paper 254, p. 93, 1910.
[c] Average for 36 years.
[d] Average for 29 years.
[e] U. S. Geol. and Geog. Surveys W. 100th Mer. Rept., vol. 1, p. 209, 1889.
[f] Average for 20 years.
[g] Average for 26 years.
[h] Average at Laporte.

SUMMARY.

The rate in Indiana probably is not indicated accurately by these data except possibly by those for the Carroll County, Sandusky, Terre Haute, and Michigan City wells, which give figures that appear reasonably accordant.

IOWA.

TEMPERATURES.

A report of the State Geological Survey[1] and a report by Norton and others[2] give temperatures of flows from many deep wells in Iowa. Doubtless most of the figures are correct, but for most of the wells either the flows are known to be from various depths or no facts are given as to their source. Some of the wells are pumped, a condition which is unfavorable for accurate results, especially if the air lift is used. The 3,000-foot well at Des Moines is one in which many flows mingle and the water is pumped to the surface. Temperatures of flows from several of the deep wells at Davenport were taken for me by J. A. Udden in 1898, but unfortunately in most of the wells there are mingled flows. The well at Ames was tested by S. W. Beyer,[3] who lowered a Miller-Casella thermometer and took readings every 100 feet.

[1] Iowa Geol. Survey Rept., vol. 6, pp. 294–299, 1897.
[2] Norton, W. H., and others, Underground water resources of Iowa: U. S. Geol. Survey Water-Supply Paper 293, 994 pp., 1912.
[3] U. S. Geol. Survey Water-Supply Paper 293, p. 749, 1912.

Temperatures in wells in Iowa.

Location.	Total depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Allamakee County:						
New Albin	500	.....	51	45.7	.....	
Lansing	675,748	.....	50	45.7	.....	Source of water not given.
Waukon, 3 miles north of.[a]	396	Pumps many.	52	[b]47	80	Sandstone 347 to 396 feet, with water within 137 feet of surface.
Blackhawk County:						
Waterloo	1,360	.....	56	46.8	.....	Source of water not given.
Do	1,365	.....	54	46.8	.....	
Cedar County: Tipton [c d, e]	2,696½	Pumps 225	57	[f]48.3	118	Water pumped 65 feet. "No water below 1,200 feet"; probably all from St. Peter sandstone, 1,030 to 1,070 feet.
Clayton County: McGregor.[c]	520	Many.	52	45	[g]74	Flows.
Clinton County: Clinton	1,605	500	72	48.6	69	Probably cased. Many other wells with mixed flows.
Henry County: Mount Pleasant Asylum.[h]	1,125	165	62	[i]50.2	84	Water pumped 30 feet. Water from 990 feet.
Des Moines County: [j]						
Burlington	509	15	56	[k]50.5	93	Source of flow not given.
Do	450	Many.	60	50.5	47	Flow presumably from bottom.
Do	852	500	64.5	50.5	61	Some water also at 430, 700, and 800 feet.
Do	460	40	60	50.5	48	Flow probably from bottom.
Iowa County: Amana Society.[l]	1,640	100	68	[m]47.9	81	Cased to 400 feet. Main flow begins at 1,200 feet; gradual increase to 1,640 feet.
Lee County:						
Fort Madison:						
Atlee well [n]	740	Many.	64	[o]51.9	57	Water pumped 85 feet.
Paper company	689	600	62	51.9	62	Water from about 680 feet.
Do	681	200+	65	51.9	43	Water from 607 feet.
Atchison, Topeka & Santa Fe Ry.[n]	764	Many.	60	51.9	77	Water probably from sandstone, 692 to 756 feet.
Keokuk: [p]						
Brewery	700	Many.	65	[q]51.4	51.5	
Pottery company	701	250	60	51.4	73	First sandstone 628 to 701 feet.
Y. M. C. A.	769	350	64	51.4	55.5	Water mainly from 700 feet.
Pickle company	710	250	64	51.4	42	Water from 530 feet.
Carter Co	661	5	61	51.4	8	Water mainly from 648 to 661 feet.
Mooar[r]	800	165	67	51.4	51	Cased to 600 feet; water from 800 feet.
Polk County:						
Des Moines city park	2,250	.....	70.0	[s]49.3	109	Thermometer sunk by S. W. Beyer.[t]
Do	2,000	.....	69.4	49.3	99½	
Do	1,750	.....	69.5	49.3	87	
Do	1,500	.....	69.1	49.3	75	
Do	1,250	.....	68.3	49.3	66	
Do	1,000	.....	65.4	49.3	62	Rate 250 to 2,250 feet is 138 feet to 1°.
Do	750	.....	60.5	49.3	67	Rate 250 to 1,000 feet is 75 feet to 1°.
Do	500	.....	58.2	49.3	56	Rate 1,000 to 2,250 feet is 272 feet to 1°.
Do	250	.....	55.5	49.3	.....	

[a] U. S. Geol. Survey Water-Supply Paper 293, p. 252, 1912.
[b] Dubuque average minus 0.9°.
[c] Iowa Geol. Survey Rept., vol. 6, pp. 185, 189, 200, 266–267, 1896.
[d] Mead, D. W., Hydrogeology of the Upper Mississippi Valley: Assoc. Eng. Soc. Jour., vol. 13, p. 368, 1894.
[e] U. S. Geol. Survey Water Supply Paper 293, p. 374, 1912.
[f] Cedar Rapids average plus 0.6°.
[g] Postville average.
[h] Iowa Geol. Survey Rept., vol. 6, pp. 320-321, 1896; U. S. Geol. Survey-Water Supply Paper 293, p. 535, 1912.
[i] Average for 36 years.
[j] U. S. Geol. Survey Water-Supply Paper 293, pp. 528–529, 1912.
[k] Average for 19 years.
[l] Iowa Geol. Survey Rept., vol. 6, pp. 286–287, 1896.
[m] Cedar Rapids average plus 0.2°.
[n] U. S. Geol. Survey Water-Supply Paper 293, p. 563, 1912.
[o] Keokuk average minus 0.4°.
[p] U. S. Geol. Survey Water-Supply Paper 293, pp. 564–566, 1912.
[q] Average for 46 years.
[r] U. S. Geol. Survey Water-Supply Paper 293, p. 568, 1912.
[s] Average for 38 years.
[t] U. S. Geol. Survey Water-Supply Paper 293, pp. 734–738, from Iowa College Water-Supply, Ames, 1897.

Temperatures in wells in Iowa—Continued.

Location.	Total depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Pottawattamie County: Council Bluffs.[a]	1,280	105	62	[b]50	83	Flow from 1,000 to 1,100 feet.
Scott County:						
Davenport:[c]						
Glucose works, three wells.	1,969	Many.	66.5	[d]49.4	116	Flows probably mingle.
Malting company..	800	Many.	60	[d]49.4	75	Cased to bottom.
Do	1,653	Many.	64	[d]49.4	[e]95	First flow from 1,385 to 1,585 feet.
Witts Bottling Co..	780	Many.	59.5	[d]49.4	77	
Woolen mills	1,050	Many.	60.5	[d]49.4	.....	Flows probably mingle.
Ice factory	1,050	Many.	60	[d]49.4	.....	Do.
Kimball House	1,050	Many.	59.5	[d]49.4	.....	Do.
Story County:						
Ames	2,100	.....	63.4	[f]46.8	127	Thermometer sunk by S. W. Beyer.[g]
Do	2,000	.....	64.1	[f]46.8	116	Do.
Do	1,500	.....	60.9	[f]46.8	107	Do.
Do	1,000	.....	57.0	[f]46.8	98	Do.
Do	500	.....	53.0	[f]46.8	81	Do.
Do	200	.....	51.2	[f]46.8	.....	Rate from 200 to 2,100 feet is 156 feet to 1°.
Nevada	940	200	59	[f]46.8	77	Cased 810 feet. Water at 940 feet pumped.
Wapello County:						
Ottumwa:[h]						
Water company	2,047	700	70	[i]49.3	.....	Water mostly from 1,015 feet.
Do	2,047	300	70	[i]49.3	.....	Cased to 1,200 feet and from 1,705 to 2,047 feet.
Morrell Co	1,554	1,000	64	[i]49.3	74	Water from 1,085 feet.
Iron works	1,150	Many.	62	[i]49.3	82	Water from 1,040 feet.
Y. M. C. A	800	33	65	[i]49.3	.....	Source of flow not given.
No. 3	1,702	1,500	67	[i]49.3	77	Cased to 1,360 feet.
Washington County: Washington.[j]	1,611	95	72	[k]49.4	71	Air lift pumps water 54 feet. Water from various depths; much at 1,115 feet, main supply at 1,600 feet.

[a] U. S. Geol. Survey Water-Supply Paper 293, p. 951, 1912.
[b] Omaha, Nebr., average for 46 years.
[c] Taken by J. A. Udden, 1898, with a Sargent thermometer reading 1° higher than the one in the Weather Bureau at Davenport.
[d] Average for 45 years.
[e] Calculated to 1,385 feet.
[f] Boone average of 14 years.
[g] U. S. Geol. Survey Water-Supply Paper 293, pp. 734–738, from Iowa College Water Supply, Ames, 1897.
[h] Iowa Geol. Survey Rept., vol. 6, pp. 317–320, 1897; U. S. Geol. Survey Water-Supply Paper 293, pp. 606–609, 1912.
[i] Mean of Keosauqua and Oskaloosa.
[j] Average for 35 years.
[k] U. S. Geol. Survey Water-Supply Paper 293, p. 613, 1912.

SUMMARY.

The data here given from the Iowa wells present considerable diversity in value. The Beyer determinations of temperature at 2,250 feet at Des Moines and at 2,100 feet at Ames are valuable records. They were taken with a Miller-Casella self-registering instrument at intervals of 250 feet in the Des Moines well and 100 feet at Ames. The wells were full of water and had not been disturbed for a month or more. The rates of increase in temperature, 1° in 109 feet and 127 feet, respectively, appear abnormally low and are considerably less than the rate in the 940-foot Nevada well, 9 miles east of Ames. As shown in the table there were some remarkable local variations at different depths. The rates indicated by many

records in the southeast corner of the State vary greatly. The deeper Ottumwa wells give 1° in 62½, 77½, 80, and 87 feet, and the 800-foot well at the Young Men's Christian Association Building indicates 1° in 53 feet or less. The Amana data appear to be not worth considering. Some of the Davenport data appear to be consistent and indicate a rate of 1° in 75 to 77 feet. The Keokuk, Fort Madison, and Burlington rates of 1° in 42 to 73 feet appear to be reliable, but the precise rate for each place is not deducible from the data given. The Mount Pleasant and Washington rates are reasonably consistent with the figures for the adjoining counties. The McGregor and Waukon wells, in the northeast corner of the State, although of moderate depth, appear to afford reliable data. The same is true of Council Bluffs, in the extreme western part of the State, where the rate of increase is the same as in the wells at Omaha, across Missouri River—1° in 83 feet.

GEOLOGIC RELATIONS.

The Iowa wells penetrate limestones, shales, and sandstones of Carboniferous to Cambrian age. They lie nearly horizontal, but most of the State is occupied by a broad, open syncline whose axis extends from east and northeast to southwest and passes near Muscatine, Oscaloosa, Indianola, Osceola, and Bedford. The Algonkian rocks are deeply buried, for they were not reached by the 2,696½-foot hole at Tipton, and no igneous rocks or marked local disturbances are known to be near the wells of which data were recorded. The deeper borings and those in the northeast corner of the State draw from the sandstones of Cambrian or Ordovician age, especially the St. Peter sandstone, which is the source of supply at Tipton and Washington and is about 1,300 feet below the surface at Ottumwa, 1,100 feet at Davenport, 950 feet at Burlington, and 900 feet at Keokuk. The Ames, Amana, Davenport, and Des Moines holes penetrate the Jordan sandstone; the Nevada well draws from much higher limestones of Silurian age. The shallow Burlington and Fort Madison wells draw from strata considerably above the Jordan sandstone. When these facts are considered in connection with the rates of increase given in the table there appears to be no connection between the geologic horizon and the rate, so far as is indicated by the data available.

The abrupt change of rate from 1° in 75 feet to 1° in 272 feet at a depth of about 1,000 feet in the Des Moines well occurs just below the base of the Devonian.

KANSAS.

TEMPERATURES.

Sixteen temperature determinations were obtained in Kansas, part of them by me and my assistants, who lowered thermometers to the bottom of the wells. Others are given in publications, notably in the report on mineral water.[1] The following are the data:

Temperatures in wells in Kansas.

Location.	Total depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Allen County: Iola [a]	720	7	61	.....	.....	Gassy water from below 626 feet.
Bourbon County:						
Fort Scott [b]	621	Many.	67.5	[c] 56	54	Good flow, begins at 510 feet.
Do	700	Pumps.	67	56	.....	
Cherokee County: Columbus [b]	1,400	.....	75.2	[c] 56.5	75	Cased to bottom.
Crawford County:						
Cherokee [d]	913?	.....	71.5	[e] 56.4	60½	Cased 300 feet. Water pumped from 100 feet.
Girard [f]	980	.....	75	[g] 56.3	52	Cased 376 feet. Water pumped from 150 feet.
Decatur County: Kanona	1,540	.....	89.7	[h] 51.6	40½	In progress July, 1903. Thermometer sunk by N. H. Darton.
Douglas County: Lawrence. [h]	1,400	.....	[d] 65.5	.....	.....	Flows from depth not given.
Ellsworth County: Ellsworth. [i]	730	.....	70	[k] 55	49	Thermometer sunk by C. A. Fisher in 1900, 2½ hours.
Finney County: Garden City.	435	.....	63.5	54	[l] 46	Thermometer sunk by W. D. Johnson, July, 1898.
Meade County:						
Meade	325	.....	71.5	[m] 56.5	22	Thermometer sunk by W. D. Johnson in July, 1898. Water was within 42 feet of surface.
Do	265½	.....	61.7	56.5	51	Flows.
Montgomery County:						
Coffeyville, 1 mile northeast of.	610	.....	69	[n] 57.7	54	Oil well not in use. Thermometer sunk by E. G. Woodruff.
Caney, 1 mile west of	2,775	.....	73	57.7	181	Abandoned boring. Thermometer sunk by E. G. Woodruff.
Independence [o]	1,100	.....	62	[p] 57.8	.....	Source of flow not given.
Morton County: Richfield [q]	600	6.3	66	[r] 56	57	Flows from 570 feet. In red beds 265 to 600 feet.
Neosho County: St. Paul [t]	700	.....	55	.....	.....	Gassy water.
Pawnee County:						
Larned [s]	750	250	65	[t] 54.3	70	Pressure 23 pounds. Brine from 743 feet. Flow also at 430 feet cased off.
Do	743	240	65	54.3	69½	Thermometer lowered by C. A. Fisher, 1900.

[a] Kansas Univ. Geol. Survey, vol. 7, p. 251, 1902.
[b] Idem, p. 265.
[c] Average for 10 years.
[d] Kansas Univ. Geol. Survey, vol. 7, p. 39, 1902.
[e] Kansas Univ. Geol. Survey, vol. 7, p. 268, 1902.
[f] Kansas Univ. Geol. Survey, vol. 7, p. 151, 1908.
[g] Columbus average minus 0.2°.
[h] Norton average for 18 years.
[i] Average for 20 years.
[j] On ranch of J. Cochran, SW. ¼ NW. ¼ sec. 15, T. 15, R. 8.
[k] Salina average minus 0.1°.
[l] Average for 21 years.
[m] Ashland average for 18 years.
[n] Independence average minus 0.1°.
[o] Kansas Univ. Geol. Survey, vol. 7, p. 150, 1902.
[p] Average for 38 years.
[q] Senate Committee on Use and Reclamation of Arid Lands Rept., vol. 4, p. 60, 1890.
[r] Ulysses average minus 1°.
[s] Kansas Univ. Geol. Survey, vol. 7, p. 158, 1902.
[t] Marksville average minus 0.2°.

[1] Bailey, E. H. S., Kansas Univ. Geol. Survey, vol. 7, 343 pp., 1902.

Temperatures in wells in Kansas—Continued.

Location.	Total depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Rice County:						
Lyons Gas & Oil Co....	950	.....	71½	[a] 54.4	56	Salt shaft. Thermometer lowered by C. A. Fisher, 1900. Down three hours.
Lyons, salt mine.....	1,083	.....	69	54.4	74	Salt shaft. Thermometer placed in bottom by C. A. Fisher.
Sterling, NE. ¼ SW. ¼ sec. 22.	946	.....	71½	54.4	56	Thermometer lowered by C. A. Fisher, 1900. Down 4 hours. Water is within 3 feet of surface. Rock salt and shale 710 to 946 feet.

[a] Ellinwood average for 21 years.

SUMMARY.

Most of the Kansas observations are in fairly close accord as to rates of increases in temperature. The principal exception is that of the Caney boring, which shows a temperature of only 73° at a depth of 2,775 feet. Possibly this is due to gas escape. This hole and those at Independence, Coffeyville, Fort Scott, Girard, Cherokee, and Columbus are all in the southeast corner of the State. The average rate exclusive of Caney is 1° in slightly less than 60 feet. The group of four holes in central Kansas have rates of 1° in 48.7 to 56.2 feet, but the rate decreases to 1° in 74.2 feet in the deep shaft at the Lyons salt mine. Four wells in the western part of the State have rates of 1° in 41, 47, 51, and 57 feet; the first and third represent careful measurements. There is a great difference in the rates of the two wells at Meade as determined by Johnson.

GEOLOGIC RELATIONS.

The wells in Kansas penetrate a variety of sedimentary formations, but the strata are nearly horizontal and no igneous rocks are known to exist near any of the holes in the list. The wells in the southeast corner of the State are in limestone, shale, and sandstone of Carboniferous age, some of the deeper ones penetrating the upper part of the Mississippian. The Ellsworth, Lynn, and Sterling wells are in the salt series of the Permian. The Richfield well is in the red beds of the Permian, Garden City, and Kanona in the Dakota sandstone (Upper Cretaceous). The Meade wells reach red beds under a thick mantle of sand and gravel of Tertiary age. The high rate of increase in the 325-foot well at Meade, 1° in 21.7 feet, may be related to a fault supposed to extend along one side of the artesian basin.

KENTUCKY.

TEMPERATURES.

Very few records of well temperatures have been reported from Kentucky. The most important one is that of the 2,086-foot well sunk in 1857–58 at Louisville, which indicates a rate of increase of 1° in 106 feet if the water comes from the bottom.

Temperatures of wells in Kentucky.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Jefferson County: Louisville..	2,086	264	[a] 76½	[b] 56.8	106	
			[c] 82½	56.8	81	
Jessamine County: Harrisburg (on Kentucky River).	485	.....	77	[d] 56.1	23	Flow of poor water.
Meade County: Fountain Farm.[e]	428	.....	64	[f] 56.2	57	Gas and brine.

[a] Owen, D. D., Geological reconnaissance of Arkansas, p. 61, 1860. Another report gives a temperature of 86¼°, which indicates a rate of 1° in 71 feet.
[b] Average for 44 years.
[c] Am. Jour. Sci., 2d ser., vol. 27, pp. 174–178, 1859.
[d] Richmond average for 22 years.
[e] Report on the occurrence of petroleum, natural gas, and asphalt rock in western Kentucky, based on examinations made in 1888 and 1889: Kentucky Geol. Survey, p. 179, 1891.
[f] Irvington average for 19 years.

SUMMARY.

The old Louisville artesian well with a large flow should give a reliable indication of the rate of increase, but two widely different temperatures are reported. The result for the Harrisburg well is dubious. The Fountain Farm well is gassy, but the rate is reasonable.

GEOLOGIC RELATIONS.

The strata penetrated by the wells listed in the table are limestone and shale of Paleozoic age on the west slope of the Cincinnati arch, and the dips are very low. The Louisville hole penetrates Devonian, Silurian, and Ordovician strata. The Fountain Farm well penetrates Mississippian limestone to the Devonian black shale.

LOUISIANA.

BELLE ISLAND.

The most significant determination of underground temperature in Louisiana is one made for me by I. N. Knapp in February, 1909, during the sinking of a 3,171-foot boring at Belle Island, near Morgan City. A Darton thermometer was lowered to various depths with the following results.:

Temperatures at different depths in hole at Belle Island, La.

Depth (feet).	Temperature (° F.).	Remarks.
427	75	In salt water.
764	79	24 hours after drilling ceased.
975	82	Dry salt.
1,625	82	Dry hole.

At 427, 764, and 975 feet the instrument was down 36 hours. It was sent down again 24 hours later, obtaining closely accordant results. At 1,625 feet there was much gas, which caused a diminished temperature, so no observations were made at greater depths. The beds below 211 feet were salt or salt bearing. The rates of increase were as follows, as calculated from a mean annual temperature of 68.7° (Franklin average for 24 years plus 0.2°):

Depth per degree of increase in temperature in hole at Belle Island, La.

	Feet.		Feet.
Surface to 427 feet	68	427 to 764 feet	84
Surface to 764 feet	74	427 to 975 feet	78
Surface to 975 feet	73	764 to 975 feet	70

MISCELLANEOUS DATA.

Although there are many flowing wells in Louisiana they afford but few reliable data as to the geothermal gradient. Harris [1] gives results of his own observations for many wells, notably those in St. Tammany and Tangipahoa parishes, and Veatch [2] gives records from various sources, but only in a few of the records is information given as to the source of the water. However, as the pressures are such as to indicate considerable depth, and as the materials are soft, it is probable that the wells are cased to or nearly to the bottom. If so, the temperature records are valuable as indicating approximately the rate of increase with depth.

[1] Harris, G. D., U. S. Geol. Survey Water-Supply Paper 101, pp. 33-60, 1904.
[2] Veatch, A. C., U. S. Geol. Survey Prof. Paper 46, pp. 208-223, 1906.

Temperatures in wells in Louisiana.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Caddo Parish: Shreveport	996	Many.	84.0	[a] 65.1	53	Brine with gas.
Calcasieu Parish: Welsh	190	1,200	71.5	[b] 67.4	46	
Catahoula Parish: Leland	1,550	10	86.5	[c] 66.8	78	Do.
Orleans Parish:						
New Orleans	1,229	55	81.5	[d] 68.2	92	Do.
New Orleans, 1 mile west of.	[e] 900	12	79	68.2	83	
Ouachita Parish: Monroe	385	Many.	71	[f] 65.6	71	
De Soto Parish: Frierson	1,500	10	70	[g] 64.8	.....	Flows at 241 to 281 and 998 to 1,275 feet; probably mingle.
St. Tammany Parish:						
Covington:						
Dummet	572	20	74	[h] 66.8	80	
Dixon Academy	.....	Many.	72.6	66.8	.....	
Claiborne	630	30	73	66.8	101	
Courthouse, 1901	.....	.....	73	66.8	.....	
Courthouse, 1903	.....	.....	72.4	66.8	.....	
John Dutch	600	20	74	66.8	83	
H. Hallen	520	30	72	66.8	100	
Hernandez, 2 miles north of.	610	38	73	66.8	98	
Hernandez	610	40	72¼	66.8	111	
Maison Blanche	480	16	72¼	66.8	87	
Abita Springs	545	54	73	66.8	88	
Do	574	27	73	66.8	93	
Do	526	56	74	66.8	73	
Mandeville	217	28	69.5	[i] 67	87	
Do	247	Many.	71	67	62	
Chinchuba	325	Many.	72	67	65	
Sabine Parish: Negreet	630	30	70	[j] 65.4	137	From 630 feet, but possibly higher flows mingle.
Tangipahoa Parish:						
Ponchatoula	232	3	71	[k] 67	58	
Ponchatoula, 3 miles north of.	170	10	69.5	67	70	
Hammond	272	20	70.5	67	80	
Do	225	2½	70	67	75	
Do	330	24	71.5	67	73	
Do	265	7	71	67	66	
Do	265	28	71	67	66	
Do	377	24	71	67	94	
Do	300	25	71	67	75	
Hammond Ice Co	340	.....	72	.....	68	
Hammond:						
1½ miles south-southwest of.	212	8	69	67	106	
Do	140	3	69	67	70	
1½ miles south of	309	30	72	67	62	
½ mile southeast of	318	45	70.5	67	91	
Do	302	24	70.5	67	86	
1 mile south of	[l] 380	15	70.6	67	106	
1 mile east of	235	.....	69	67	.....	
1½ miles south-southeast of.	298	5½	70¾	67	80	
Vermillion Parish: Gueydan, 3 miles southwest of.	190	8	73	[m] 68.3	40	
Winn Parish: Drake Salt Works.	[n] 1,011	18	75	[o] 66.	123	Brine from Cretaceous.

[a] Average for 45 years.
[b] Lake Charles average.
[c] Natchez, Miss., average for 29 years.
[d] Average for 45 years at Station 1.
[e] Cased to bottom.
[f] Monroe average for 28 years.
[g] Grand Cane average for 22 years.
[h] Average for 24 years.
[i] Covington average plus 0.2°.
[j] Average at Nacodoches, Tex.
[k] Hammond average for 24 years.
[l] Water from 340 to 380 feet.
[m] Abbeville average.
[n] Veatch, A. E., Louisiana Geol. Survey Rept. for 1902, pp. 51–64, 1903.
[o] Mean at Dodson, 1916.

Water from pumped wells 197 to 315 feet deep in Bossier Parish is reported to have temperatures from 64° to 66°; from a 225-foot well at Belcher, in Caddo Parish, 66°; from wells 137 to 280 feet deep at Shreveport, 66° to 68°; and from several wells 115 to 368 feet deep in Webster Parish, 65° to 66°.[1] All these figures are so near the mean annual air temperature that they throw no light on the rate of increase.

SUMMARY.

None of the rates of the deeper wells given in the list are close approximations. In the Frierson and Negreet wells probably the mingling of flows gives a lower temperature than the water from the lower flow would show. The wells of Tangipahoa Parish are too shallow to be reliable within close limits, but they give an average rate of 1° in very nearly 80 feet.

GEOLOGIC RELATIONS.

All the wells in Louisiana are in the great Coastal Plain sedimentary series of the Mississippi embayment, but several horizons are tapped. The strata are sands, clays, and limestones of Cretaceous and Tertiary age, dipping at low angles in various directions. In northern Louisiana there is a general dip to the east into a basin whose bottom is near Vicksburg, Miss., at a rate of generally from 7 to 10 feet to the mile, with few local variations, some of which are due to sharp local uplifts. This basin widens and deepens to the south and becomes a deep, wide trough containing a great thickness of Tertiary strata. The briny waters of the Shreveport well come from the Nacatoch sand in the Upper Cretaceous, and the brine at the Drake salt works is also from the Cretaceous. Brine from the Leland well is believed to be from the Eocene Yegua ("Cockfield") formation, 1,500 feet higher. The beds tapped by the shallow wells of Calcasieu, St. Tammany, and Tangipahoa parishes are high in the Tertiary.

MARYLAND.

Only one well temperature was obtained from Maryland—that of the 140-gallon flow of saline water from the deep well at Crisfield, Somerset County, on the eastern peninsula. The flow comes from a depth of 1,025 feet in the Potomac group, and the temperature, 79°, was determined by Mr. John Buxton with a reliable thermometer sent to him for the purpose. As the mean annual temperature at Pocomoke City, not far away, is 57.4°, this determination indicates a rate of increase of 1° in 47.4 feet.

[1] Veatch, A. C., U. S. Geol. Survey Prof. Paper 46, pp. 201–207, 217–223, 1906.

MICHIGAN.

SOURCES OF INFORMATION.

Temperature observations that have been made in deep borings and deep mines in Michigan throw important light on the rate of increase in temperature underground. Some of these have been made by A. C. Lane,[1] in part with thermometers which I furnished. On account of the differences in the geology of the two areas it is best to present the results of observations made in southern and central Michigan separately from those of observations made in the area of older rocks in the northern peninsula. Lane has considered the probable mean annual temperature of the northern peninsula and also gives temperatures in shallow borings and in upper levels in certain copper mines.

NORTHERN PENINSULA.

Many determinations of underground temperature are available for the northern part of Michigan, mainly in connection with the deep mines.

In 1895 Alexander Agassiz [2] reported the results of a series of observations made in copper mines of the Calumet & Hecla Co. on Keweenaw Point. This point, which extends 70 miles out into Lake Superior, consists of a series of old igneous and sedimentary rocks dipping 7°–55° and overlain by Cambrian sandstone. The mines are mostly in the older series. The temperatures were taken at intervals, but only those at 105 feet and 4,580 feet were published. Negretti and Zambra thermometers were used, placed in 10-foot holes, slightly inclined upward, and left from one to three months, the holes plugged with wood and clay. The results were 59° and 79°, a difference of only 20° for the 4,475 feet, or an increase of 1° in 223.7 feet. However, if the 59° observation is disregarded and the increase to 4,580 feet calculated from a mean annual air temperature of 43° [3] the result is 1° in 127 feet, which is borne out by other observations. It is evident that the reading of 59° at 105 feet was defective, because it is 16° to 20° higher than the mean annual air temperature.

In a letter to J. D. Everett in 1896,[4] Agassiz stated that further observations had shown that the rate was "different from what it was believed to be when the preliminary announcement was made."

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[1] Lane, A. C., The Keweenaw series of Michigan: Michigan Geol. and Biol. Survey Pub. 6, vol. 2, pp. 757–773, 1911; Am. Jour. Sci., 4th ser., vol. 9, p. 435, 1900.

[2] Agassiz, Alexander, On underground temperatures at great depth: Am. Jour. Sci., 3d ser., vol. 50, pp. 503–504, 1895.

[3] The mean annual air temperature at Calumet is 39.7° (29-year average), but shallow-water and mine workings indicate several degrees higher, according to Lane.

[4] Underground temperatures: British Assoc. Adv. Sci., Report of 71st meeting, p. 65, 1901.

In 1886 Wheeler [1] presented to the St. Louis Academy of Sciences an account of temperature observations in copper mines of Keweenaw Point. Wheeler's results are given in the following table:

Temperature observations in copper mines on Keweenaw Point, Mich.

Mine.	Depth.	Temperature (°F.).	Depth per degree of increase in temperature (feet).	Temperature at certain depths.[a]
Atlantic	907	51.6	99½	43.6° at 111 feet.
Central	1,950	61	101	42.6° at 90 feet.
Conglomerate (Delaware or Manitou)	617	48.3	95	42.8° at 90 feet.
Quincy	1,931	58.5	122	43° at 111 feet.
Osceola	996	54.5	76½	42.3° at 136 feet.
Tamarack	2,240	62	110½	43° at 136 feet.

[a] The figures in this column were used in calculating the rates of increase.

Wheeler states that the most satisfactory results were obtained in the Atlantic mine, where observations at intermediate stations gave an accordant rate. The Conglomerate mine is 36 miles farther east. The rate in the Tamarack mine may be vitiated by the proximity of active mining. All the mines were nearly dry. Wheeler suggests that the low rate of increase in this district may be due to the proximity of Lake Superior, with its great volume of cool water (38.8°).

Temperature observations in mines and holes in northern peninsula of Michigan.[a]

Locality.	Depth (feet).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Freda well[b]	950	55.6	.....	84	Temperature 45½° at 100 feet.
Victoria mine[b]	[c] 1,350	57	±44	104	Eighteenth level.
Champion mine[b]	465	45.8	44	.....	9 to 250 feet west of shaft.
Do	1,335	52	44	.....	Twenty-fourth level, 140 feet west.
Do	1,500	55	44	.....	End of twenty-sixth level.
Do	1,650	56.5	44	111	End of twenty-eighth level, 750 feet from fifth shaft.
Vulcan iron mine[b]	1,090	56	44	83	
Do	1,210	56	44	94	Surface water 44°.
Republic iron mine[b]	1,153	55	44	105	
Do	1,435	59	44	95½	In water.
Central copper mine	2,400	61	44	141	Foot of No. 2 shaft, thirtieth level.
Centennial mine	1,850	62	44	180	Foot of shaft.
Do	(?)	69	.....	(?)	Slope 3,100 feet long on Osceola lode, 72° during previous summer.
Ojibway mine	680	50	44	113	On 1,225-foot slope, 33° dip.
Franklin, jr., mine	1,600	61	44	94	Twenty-first level cross cut.
Old Franklin	3,200	62–63	44	169	Third level; G. Pope, observer.

[a] Lane, A. C., The geothermal gradient in Michigan: Am. Jour. Sci., 4th ser., vol. 9, p. 435, 1900; Michigan Geol. Survey Ann. Rept. for 1901, pp. 244–251, 1902.
[b] Lane, A. C., The Keweenaw series of Michigan: Michigan Geol. and Biol. Survey, Pub. 6, vol. 1, pp. 757–773, 1911.
[c] Vertical depth not given.

[1] Wheeler, H. A., Temperature observations at the Lake Superior copper mines: Am. Jour. Sci., 3d ser., vol. 32, pp. 125–129, 1886.

Temperature observations in mines and holes in northern peninsula of Michigan.—Con.

Locality.	Depth (feet).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Tamarack	4,400	84	44	110	R. M. Edwards, observer.
Do	5,223	85	44	127	Do.
Do	5,367	88–91.4	44	93½	Bottom; observed by Lane in damp mud.
Tamarack, No. 5	4,662	82	44	123	W. E. Parnall.
Do	4,900	87	44	114	J. Hull, mine inspector.
Quincy mine[a]	1,080	57	44	83	Diamond-drill hole, 3 days.
Do	2,941	64.5	44	143½	Diamond-drill hole, 5 days.
Do	2,941	67.5	44	121	Breast of drift.
Do	3,090	68.5	44	126	Do.
Do	3,196	69	44	128	Do.
Do	3,403	71	44	126	Do.
Do	3,620	75	44	117	Driveway between shafts.
Do	3,816	79, 80	44	106	Breast of drift.
Do	3,875	76	44	121	Diamond-drill hole, 40 hours.
Calumet & Hecla stamp mill, Lake Linden, Houghton County, SW. ¼ sec. 6, T. 55, R. 32.	500	47.5	44	143	Two wells, 1,502 and 1,508 feet. Flow 50 gallons. All in sandstones.
Do	1,000	51.5	44	133	
Do	1,490	55.5	44	130	Rate indicated by difference between figures for 500 and 1,490 feet is 10 in about 124 feet.
Lake Superior mine, Ishpeming.	900	50	44	150	Thermometer 20 minutes in 5-foot hole in shaft.

[a] The depths here given assume the surface to be 500 feet above Lake Superior, for in the original paper depths are given with the lake as the datum and the surface is irregular. Temperatures were all taken by S. Smillie, engineer.

The temperature of 57° at 1,080 feet in the Quincy mine appears anomalously high when compared with the record at greater depths. The rate of increase calculated from the difference between the temperature at 1,080 feet and 3,875 feet is 1° in 147 feet; from 2,941 to 3,875 feet it is 1° in 81 feet on the basis of a temperature of 64.5° in the bore hole, and 1° in 110 feet on the basis of an observation of 67.5° in the breast of a drift.

CENTRAL AND SOUTHERN MICHIGAN.

Temperatures in deep wells in central and southern Michigan.

Locality.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Alpena County: Alpena[a]	698–711	200	53	[b] 41.8	62	Main supply from 698 to 711 feet; surely below 588 feet.
Bay County:						
Bay City[c]	3,455	.....	97	[d] 46.5	68½	Thermometer 5688 down 8 hours.
Do	2,934	.....	90.1	46.5	67	Thermometers 5688 and 5690 down half an hour.
			90.2	46.5	66½	
Do	2,282	.....	77	46.5	75	Thermometers 5688 and 5690 down half an hour.
			77	46.5	75	
Do	1,793	.....	71	46.5	73	Thermometer 4708 down 50 minutes.
Do	1,304	.....	65	46.5	70	Thermometer 4708 down 1 hour.

[a] Lane, A. C., Am. Jour. Sci., 4th ser., vol. 9, p. 435, 1900.
[b] Average for 44 years.
[c] Lane, A. C., op. cit., pp. 434–438. Test by C. A. Davis with Darton thermometers after drilling had ceased two months; bore full of heavy brine. The tests at 2,282 and 1,793 feet were regarded as too short in duration.
[d] Average for 21 years.

Temperatures in deep wells in central and southern Michigan—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Benzie County:						
Frankfort [a]	2,200	280	58	[b] 44.9	[c] 61	Water from 800 feet; surely below 590 feet.
Do [d]	2,200	.....	56	44.9	[c] 72	Do.
Do	1,800	.....	54	44.9	[c] 88	Do.
Berrien County: Niles	1,438	15	60	.....	.....	
Cheboygan County:						
Cheboygan [e]	1,380	.....	61.6	[f] 42.6	71½	Near base of Salina formation.
Do [g]	2,700	.....	73	42.6	89	The rate from 1,360 to 2,700 feet is 118 feet to 1°.
Cheboygan waterworks	408	.....	[h] 51.8	42.6	44	
Burt Lake [i]	464	4(?)	51	42.6	55	
Crawford County:						
Grayling [j]	2,600	.....	95.9	[d] 42.7	49	
Do	2,376	.....	93.8	42.7	46½	Thermometer 7815 down 1 hour to 2½ hours.
Do	2,150	.....	89	42.7	46½	
Do	900	.....	58.4	42.7	[k] 57	
Do	500	.....	51.8	42.7	55	
Emmet County: Petoskey	575	750	50	[l] 43.3	86	
Genesee County: Flint [m]	376	8	52	[n] 45.9	61	Water at 376 feet.
Grand Traverse: Traverse City. [o]	417	.....	51	45.9	82	
Gratiot County:						
Alma [p]	2,863	Flows.	98	45.6	54½	Temperature of water brought up in sand pump.
Alma, same well	900	.....	69.6	45.6	37½	Test by A. C. Lane, 1900.
Ingham County:						
Lansing [q]	1,400	1	58.5	46.7	.....	Saline water; source not known.
Mason [o]	400	.....	53	46.7	.....	
Ionia County:						
Ionia [o]	400	Many.	55	[r] 46.8	44	Water from 362 feet.
Do	340, 540	.....	52.3	46.8	.....	
Do	320	.....	53.8	46.8	46	
Lenawee County:						
Britton [s]	1,617	.....	67.6	[t] 48	83	
Lenawee	945	.....	59	48	86	
Mackinac County: St. Ignace [u]	1,155	Many.	51	40.9	[v] 57	Flow at 575–681 feet; some also at 1,040 feet.
Macomb County: Mount Clemens. [w]	1,265	.....	56	[x] 47.8	79	Water from 700 feet.

[a] Michigan Geol. Survey, 1881–1893, p. 59.
[b] Average for 13 years.
[c] Calculated to 800 feet.
[d] Lane, A. C., Am. Jour. Sci., 4th ser., vol. 9, p. 435, 1900.
[e] Taken by A. C. Lane (Geol. Soc. America Bull., vol. 13, 1903) with Darton thermometer 7812. Down 1 hour on bailer. Temperature 51.8° at 408 feet.
[f] Average of 20 years to 1908.
[g] Tested by F. P. Rust, contractor, who determined other temperatures with thermometer 9114 as follows: 100 feet, 53°; 400 feet, 51°; 700 feet, 5,1.5°; 1,000 feet, 55°; 1,300 feet, 60°; 1,400 feet, 60°; 1,700 feet, 63°; 1,800 feet, 65°; 2,000 feet, 65°; 2,300 feet, 68°.
[h] Taken by A. C. Lane with Darton thermometer 7536.
[i] Leverett, Frank, U. S. Geol. Survey Water-Supply Paper 182, p. 363, 1907. Other wells with flows 46° to 48°.
[j] Lane, A. C., op. cit., and Michigan Geol. Survey Ann. Rept. for 1901, p. 250, 1902.
[k] Rate of increase from 500 to 2,600 feet is 48 feet to 1°.
[l] Average for 27 years.
[m] Cooper, W. F., U. S. Geol. Survey Water-Supply Paper 102, p. 492, 1904.
[n] Average for 28 years.
[o] Leverett, Frank, and others, U. S. Geol. Survey Water-Supply Paper 183, pp. 16, 242, 324, 1907.
[p] Michigan Geol. Survey Rept., 1881–1893, pp. 45–46, 1895. This report is somewhat discredited by A. C. Lane in Am. Jour. Sci., 4th ser., vol. 9, p. 435, 1900, but accepted in Michigan Geol. Survey Rept. for 1901, p. 249.
[q] Michigan Geol. Survey Rept., 1881–1893, p. 66, 1895.
[r] Grand Rapids average for 28 years minus 1.3°.
[s] Lane, A. C., Michigan Geol. Survey Rept. for 1901, p. 249, by probable misprint gives deeper temperature (53°) but with data indicating that it is 67.6°.
[t] Hillsdale average for 20 years plus 0.6°.
[u] Michigan Geol. Survey Rept. 1901, p. 248, 1902.
[v] Calculated to 575 feet.
[w] Cooper, W. F., op. cit., p. 496.
[x] Average for 17 years.

Temperatures in deep wells in central and southern Michigan—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Midland County:						
Midland [a]	1,205	Flow.	62.5	[b] 46.1	73½	
Ingersoll [c]	625	.....	52	46.1	105	
Muskegon County:						
Muskegon, Ryerson well	1,150	.....	67.2	[d] 46.7	56	Plugged at 1,200 feet; full of water; flows from base of drift at 240 feet are 53° to 53½°.
Do	650	.....	58.7	46.7	54	
Do	240	.....	53.2	46.7	37	Rate of increase from 240 to 1,150 feet is 1° in 65 feet.
St. Clair County: [e]						
St. Clair	1,635	.....	71.2	[f] 45.3	63	Salt well; idle for months.
St. Clair, Oakland well	1,200+	P'mp'd	69	45.3	56+	
Port Huron	300	.....	54.2	45.3	.....	
Do	600	.....	55.3	45.3	60	
Do	838	.....	57.5	45.3	69	Rate of increase from 300 to 838 feet is 1° in 163 feet.
Saginaw County:						
Saginaw, salt well	617	.....	54	[g] 46.3	80	
Do	531	.....	51	46.3	113	Rate of increase from 293 to 617 feet is 1° in 81 feet.
Do	293	.....	50	46.3	80	
Do	102	.....	47	46.3	.....	Rate of increase from 102 to 617 feet is 1° in 75 feet.

[a] Lane, A. D., Am. Jour. Sci., vol. 9, p. 434, 1900.
[b] Average of Bay City minus 0.4°.
[c] Leverett, Frank, and others, U. S. Geol. Survey Water-Supply Paper 183, pp. 16, 242, 324, 1907.
[d] Average for 20 years.
[e] Michigan Geol. Survey Rept. 1901, p. 248, 1902.
[f] Port Huron average for 42 years.
[g] Average for 22 years.

MINNESOTA.

Few temperatures of flows from wells in Minnesota have been reported and the source of the flows is uncertain. The large flow from a 467-foot well at Winona is stated to have a temperature of 54°, which may indicate a rate of increase of 1° in 47 feet if the water is from the bottom. This well penetrates sandstones of Cambrian age which lie on granite at a depth of about 500 feet. The beds are nearly horizontal. The 600-gallon flow from a 707-foot well at Henderson, in Sibley County, is stated to have a temperature of 50°, but doubtless part of the water is from beds some distance above the bottom.

MISSISSIPPI.

TEMPERATURES.

Temperatures of several flowing wells in Mississippi have been recorded by G. D. Harris[1] and others, and as most of the wells flow in large volume and appear to be cased to the bottom the temperatures indicate approximate rates of increase. The Biloxi well, with readings at 500 and 900 feet, is of particular interest.

[1] U. S. Geol. Survey Water-Supply Paper 101, p. 31, 1904.

Temperatures in wells in Mississippi.

Locality.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet to 1°).	Remarks.
Hancock County: Bay St. Louis	700	Many.	78	[a] 57.4	66	Flow.
Harrison County:						
Biloxi	500	100	79.5	[b] 68	43	First flow.
Do	900	Many.	82.5	68	62	
Pass Christian	700	50	71	[c] 68	.....	May be mixed flow, 400 and 700 feet.
Jackson County: Scranton	774	25	74	68	129	"Cased to bottom."
Lowndes County: Columbus	400	Many.	70	[d] 63.4	60	Sandstone 300 to 325 feet.
Madison County: Canton	1,021	170	74	[d] 64.7	109	
Warren County: Vicksburg [e]	1,100	Few.	70	[f] 64.8	211	Saline water, Wilcox group.
Yazoo County: Satartia	588	14	70	[g] 64.8	113	

[a] Pearlington average for 29 years.
[b] Average for 26 years.
[c] Biloxi average.
[d] Average for 29 years.
[e] U. S. Geol. Survey Prof. Paper 46, pp. 226–227, 1906.
[f] Average for 46 years.
[g] Yazoo City average for 23 years.

SUMMARY.

The rates of increase deduced in Mississippi show considerable variation, but this may be due, in part at least, to lack of information as to source of water, notably in the wells at Canton, Vicksburg, and Sartartia. If, as stated, the Scranton well draws from the bottom, a low rate is indicated.

GEOLOGIC RELATIONS.

The Bay St. Louis, Biloxi, Pass Christian, and Scranton wells are in the higher Tertiary strata of the southern part of the State. All these strata dip gently to south or west. The Vicksburg, Sartartia, and Canton wells are deep in the Tertiary. The Columbia well is in the Cretaceous.

MISSOURI.

TEMPERATURES.

About 50 well temperatures have been obtained for Missouri, some of them taken by Schweitzer[1] and Shepard,[2] who were competent observers, and others by various persons who may or may not have obtained reliable figures. The depth from which the flows may

[1] Schweitzer, Paul, A report on the mineral waters of Missouri: Missouri Geol. Survey, vol. 3, 256 pp., map, 33 pls., 1892.
[2] Shepard, E. M., Underground waters of Missouri; their geology and utilization: U. S. Geol. Survey Water-Supply Paper 195, 224 pp., 6 pls., 1907.

come is not indicated for some of the wells, and other wells are pumped. The following is a list of the more reliable data:

Temperatures in wells in Missouri.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Temperature increase (feet to 1°).	Remarks.
Audrain County:						
Mexico	1,125	Many.	66	[a] 53.8	92	Pumped 80 feet.
Do	1,100	Many.	66	53.8	90	Do.
Buchanan County: St. Joseph brewery.	1,805	.....	82	[b] 52.2	60.5	Mineral water.
Camden County: [c]						
Gunters	780	Many.	59	[d] 56.6	.....	Source of water not given.
Hahatonka	864	Many.	63	56.6	131	Flow from 840 to 864 feet.
Clay County: [c]						
Excelsior Springs, 1 mile north of.	1,460	Many.	67	[e] 54	112	Pumped 150 feet. Source of water not given.
Do	1,327	Many.	[a] 64.4	54	127	Pumped 60 feet.
Dunklin County: Campbell [f]	910	7	78	[g] 60.5	52	Flow from 910 feet.
Franklin County: Sullivan [c]	1,550	8	63.5	[h] 55.9	204	Six-inch casing to bottom where main flow was found.
Greene County: Springfield	720	.....	60	[i] 54.8	138	Temperature at "bottom of well." [j]
Henry County: Clinton [k]	913	400	64	[l] 56.6	175	"Cased to bottom." [m]
Howard County:						
Fayette [n]	860	Many.	61.5	[o] 53.9	113	Saline water from 860 feet.
Boonslick	1,002	20	62	53.9	.....	
Jasper County: Joplin [p]	908	16	65	[q] 56.2	103	Cased to bottom; pumped 119½ feet.
Lewis County:						
Canton [r]	900	72	60	[s] 52.5	116	Flow from 870 to 900 feet.
La Grange	850	60	61	52.5	94	Flow from 800 to 850 feet.
Do [t]	850	.....	60	52.5	.....	
Livingston County: Utica [k]	421	Few.	59	[u] 52.4	64	Cased 400 feet.
Marion County: Hannibal [k]	950	208	60	53.1	138	Flow is from considerable depth.
Montgomery County: Montgomery.	600	40	58	[v] 54	150	No data.
Pike County: Louisiana [w]	1,275	Many.	[x] 64.2	[y] 53.1	115	Cased 910 feet. Source of water not given.
Randolph County:						
Moberly	508	100	60	[z] 53.5	78	Pumps; water probably from bottom.
Randolph Springs [aa]	969	120	[y] 59	53.5	176	Flows; source of water not given.
Ralls County: Rensselaer station, 5 miles south of.	330	7	57	[bb] 53.1	77	Flows from 300 to 330 feet.

[a] Average for 28 years.
[b] Oregon average plus 0.5°.
[c] U. S. Geol. Survey Water-Supply Paper 195, p. 156, 1907. Schweitzer, Paul, Missouri Geol. Survey, vol. 3, p. 99, 1892.
[d] Warsaw average for 13 years.
[e] Liberty average for 27 years.
[f] U. S. Geol. Survey Water-Supply Paper 102, p. 392, 1904.
[g] New Madrid average.
[h] Oakfield average for 25 years.
[i] Average for 29 years.
[j] U. S. Geol. Survey Water-Supply Paper 195, p. 132, 1907.
[k] Missouri Geol. Survey, vol. 3, pp. 120–121, 1892.
[l] Warsaw average.
[m] U. S. Geol. Survey Water-Supply Paper 195, p. 118, 1907.
[n] Missouri Geol. Survey, vol. 3, pp. 141–143, 1892.
[o] Average for 31 years.
[p] Idem, p. 138.
[q] Mount Vernon average.
[r] U. S. Geol. Survey Water-Supply Paper 195, p. 45, 1907.
[s] Keokuk average plus 0.1°.
[t] U. S. Geol. Survey Water-Supply Paper 195, p. 46, 1907.
[u] Kidder average.
[v] Fulton average.
[w] Missouri Geol. Survey, vol. 3, pp. 94–95, 1892.
[x] 63.5° on July 15, 1903 (U. S. Geol. Survey Water-Supply Paper 195, p. 52, 1907).
[y] Average for 23 years.
[z] Brunswick average for 28 years.
[aa] Missouri Geol. Survey, vol. 3, p. 73, 1892.
[bb] Hannibal average for 25 years.

Temperature in wells in Missouri—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual air temperature (°F.).	Temperature increase (feet to 1°).	Remarks.
St. Louis County:						
St. Louis:						
Asylum	3,843½	.....	[a]105	[b]55.8	78.1	Granite, etc., 3,558 to 3,843 feet.
Belcher well [c]	2,200	75	73.4	[d]55.8	[e]85.3	Water from 1,515 feet; much H_2S; water-bearing sandstone from 1,502 to 1,640 feet.
Do. [f]	1,590	Many.	69	55.8	102	Water from 1,351 feet.
Union Power Co	1,470	Many.	70	55.8	103	Water pumped 70 feet.
North St. Louis	735	60	62	55.8	118	Water pumped 45 feet. Source of water not given.
Vernon County: [g]						
Nevada, near	800	120	63	[h]55	100	Flow from below 785 feet.
Nevada	{ 869 / 1,001	{Many.	67	55	72½	{Flow from below 785 feet; pumped 78 feet.
Richards	650	Few.	62	55	93	Gassy.

[a] Broadhead, G. C. (St. Louis Acad. Sci. Trans., vol. 3, p. 216, 1878), who used a registering thermometer and gave temperatures of 106° at 3,127 feet; 107° at 3,129 feet; 106° at 3,264 feet; 105° at 3,473 feet; 105° at 3,533 feet; 105° at 3,604 feet; 104½° at 3,641 feet; 105½° at 3,728 feet; and 105° at 3,800 feet, observed with thermometer reading to one-fifth of 1°.

[b] Average for 44 years.

[c] Litten, A., Belcher & Bros. artesian well (St. Louis Acad. Sci. Trans., vol. 1, pp. 80–86, 1856–1860). Another authority gives 2,199 feet (U. S. Geol. Survey Water-Supply Paper 195, p. 159, 1907).

[d] Litten gives 55.22° as deduced from observations by Engleman for 22 years, indicating a gradient of 1° to 83.3 feet.

[e] Calculated to a depth of 1,502 feet.

[f] Am. Jour. Sci., 2d ser., vol. 15, p. 460, 1853.

[g] U. S. Geol. Survey Water-Supply Paper 195, p. 104, 1907.

[h] Average for 22 years.

SUMMARY.

The data from the Missouri wells listed above appear to indicate considerable diversity in gradient, but doubtless some of this diversity is due to error, especially as to source of water. The tests by Broadhead and Litten in the deep wells of St. Louis are most valuable, giving mean rates of increase of 1° in about 78 and 85 feet. The apparent decrease of 2° from 3,127 to 3,843 feet and some other inconsistent variations are difficult to explain. Some of the shallower wells appear to indicate a diminishing rate toward the surface, but uncertainty as to source of flow and influence of pumping may affect the observations. The Clinton well, which is said to be cased to the bottom, indicates the surprisingly low rate of 1° in 175 feet, and the Sullivan well shows a rate of 1° in 153 feet. The rates indicated for the Springfield well, 1° in 138 feet; the Canton well, 1° in 132 feet; the Hahatonka well, 1° in 131 feet; and the Fayette well, 1° in 113 feet, are valid if, as is reported, all these wells are cased to or nearly to the bottom. The data from Mexico, Excelsior Springs, Hannibal, Louisiana, Montgomery, Moberly, and Randolph Springs may be defective. The relatively high rates of 1° in 52 feet indicated by the Campbell well and 1° in 53 feet by the Utica well

are exceptional but almost surely correct. The rate indicated by the St. Joseph brewery well, 1° in 60½ feet, is also regarded as reliable, although the source of the water is not given precisely.

GEOLOGIC RELATIONS.

The southeastern third of Missouri consists of a low dome in the center of which the pre-Cambrian granites and other rocks are exposed in the Iron Mountain region. West of this dome the strata dip west, and north of it they slope gently to the north and northwest. At Kansas City and northward the pre-Cambrian rocks are far below the surface. The wells included in the above list penetrate a great variety of strata, all on the north or west slopes of the dome. The 3,843-foot hole at St. Louis is the only one that reached the granite, but its water supply is derived from sandstones of Ordovician age. The wells at Moberly, Hannibal, Canton, Lagrange, Louisiana, Rensselaer, Gunters, Hahatonka, Fayette, Sullivan, Montgomery, Springfield, Nevada, and Richards all draw from sandstones in the Ordovician or Cambrian. The deep well near St. Joseph entered Mississippian limestones at 1,250 feet and possibly reached the St. Peter sandstone. The deep borings of Excelsior Springs are believed to draw their mineralized waters from the "Jefferson City limestone and base of the Pennsylvanian."[1] The well at Campbell, in the southeast corner of the State, penetrates a thick deposit of clay of the Lagrange formation (Tertiary) and draws from the sand of the upper part of the Ripley formation (Cretaceous). The well at Utica draws water from the base of the Cherokee shale (Pennsylvanian).

There is no evidence that the variations in rate of increase in temperature are related to the horizons from which the waters are derived, to structural features, or to proximity to the pre-Cambrian rocks, with the possible exception of the high rate at the Campbell well, which is in the Tertiary and Cretaceous. The St. Joseph and Utica wells which show high rates are higher in the Paleozoic succession than the wells farther east and south.

MONTANA.

ANACONDA MINE.

In 1899 H. V. Winchell made a series of observations in the Anaconda mine, near Butte. He placed Darton thermometers in drill holes at various depths and left them for several days. The following results were obtained:

[1] Shepard, E. M., op. cit., p. 58.

Temperature at different depths in the Anaconda mine, near Butte, Mont.

	Altitude (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).[a]
200-foot level	5,877	45.8	53.0
400-foot level	5,673	49.5	53.0
600-foot level	5,471	51.4	63.8
800-foot level	5,271	69.8	28.8
1,000-foot level	5,081	62.0	50.0
1,600-foot level	4,477	74.3	49.2

[a] Based on mean annual air temperature of 42°, average for 21 years at Butte.

The reading at a depth of 800 feet is abnormally high, probably on account of some local condition. The rates of increase indicated between various depths are as follows: 200 to 1,600 feet, 1° in 49.8 feet; 400 to 1,000 feet, 1° in 48.2 feet; 400 to 1,600 feet, 1° in 48.5 feet; 600 to 1,600 feet, 1° in 43.6 feet; 1,000 to 1,600 feet, 1° in 48.8 feet. S. F. Emmons made an additional observation in the Gagnon mine 1,550 feet below the surface. The Darton thermometer was placed in a 3-foot drill hole and read 79° after 48 hours and 79¼° after 7 days. As the mean annual temperature here is 42° the rate indicated is 1° in 41.7 feet. This mine is the nearest one to the latest rhyolite eruption.

MILES CITY.

The flow from a 456-foot well in Miles City, Custer County, is reported [1] to have a temperature of 57°. Its volume is 5 gallons a minute and its pressure 7 pounds. Flows were also found at 300 and 390 feet, but presumably they are cased off. The mean annual air temperature at this place is 44.1° (average for 39 years), or 12.9° less than the temperature of the flow, a difference indicating a rate of increase of 1° in 35.3 feet.

LITTLE BITTERROOT VALLEY.

Meinzer [2] has given some data on temperature in artesian wells in Little Bitterroot Valley.

[1] Nettleton, E. S., Final report on artesian and underflow investigations, pt. 2: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2.

[2] Meinzer, O. E., Artesian water for irrigation in Little Bitterroot Valley, Mont.: U. S. Geol. Survey. Water-Supply Paper 400, pp. 9–37, map, 1916.

Temperatures in artesian wells in Little Bitterroot Valley, T. 22 N., R. 23 W., Mont.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Depth per degree of increase in temperature (feet). [a]
NW. ¼ sec. 18	267	14	91	5.6
SE. ¼ sec. 20	232	365	71½	8.3
SE. ¼ sec. 20	232	400	78	6.7
NW. ¼ sec. 29	244	245	[b] 120	3.2
SW. ¼ sec. 29	260	85	99	4.7
SW. ¼ sec. 29	274	25	92½	5.6

[a] Calculated from average of mean annual air temperature at Plains and Kalispell, 43.4° plus 0.2°.
[b] Reported to have been 126° three years before; the volume of flow has also diminished.

The temperatures of flow from wells 52, 82, and 90 feet deep were 57½°, 53°, and 59½°, respectively, and flows from two of the deeper wells had low temperatures. Water in a 94-foot dug well at Lone Pine post office had a temperature of 52½°. The water occurs in a bed of sand and gravel underlying a thick mass of silt supposed to have been deposited by a lake. Meinzer suggests that the variations in temperature in these wells, which are all near together, probably indicates that the warmer water comes in part from some deeper source. The Camas Hot Springs are in the northwest corner of sec. 3, T. 21 N., R. 24 W.

NEBRASKA.

TEMPERATURES.

The well temperatures in Nebraska listed below, except the observations at Lincoln and Omaha, were obtained by G. E. Condra in a reconnaissance of the counties in the northeast corner of the State.[1] These data are not only very important in themselves but they extend the area of close observation in eastern South Dakota described in subsequent pages.

[1] Condra, G. E., Geology and water resources of a portion of the Missouri River valley in northeastern Nebraska: U. S. Geol. Survey Water-Supply Paper 215, 1908.

Temperatures in wells in Nebraska.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Boyd County:						
Lynch	797	465	79½	47.9	23.1	Flow 761 to 797 feet.
Lynch, new well	923	Many.	90	47.9	20.8	Third flow from 875 feet.
Cedar County:						
Sec. 17, T. 33, N. 1 W.	500	Many.	59	[a] 46.5	.....	Flow probably in part from 400 feet.
Sec. 17, T. 33, N. 1 W.	365	26	59½	46.5	28.0	Flow at 337 feet.
Sec. 16, T. 33, N. 1 W.	400	Many.	59½	46.5	30.8	
Sec. 16, T. 33, N. 1 W.	400	7	60	46.5	29.6	
Sec. 16, T. 33, N. 1 W.	400	7	58½	46.5	33.3	
Sec. 9, T. 33, N. 1 W.	400	7	58½	46.5	33.3	
Sec. 10, T. 33, N. 1 W.	400	15	59	46.5	32.0	
Sec. 12, T. 33, N. 1 W.	400	7	59½	46.5	30.8	
Sec. 12, T. 33, N. 1 W.	380	44	60	46.5	28.1	
Sec. 8, T. 33, N. 1 E.	360	52	59½	46.5	27.7	
Sec. 17, T. 33, N. 1 E.	420	.....	59	46.5	18.7	
Sec. 16, T. 33, N. 1 E.	360	5½	58	46.5	31.2	
Sec. 17, T. 33, N. 1 E.	454	.....	58½	46.5	37.8	
Sec. 22, T. 33, N. 1 E.	500	15–20	62	46.5	32.2	
Sec. 24, T. 33, N. 1 E.	350	.....	60	46.5	25.9	
Sec. 30, T. 33, N. 1 E.	530	30	63	46.5	32.1	
Sec. 34, T. 33, N. 2 E.	280	.....	60	46.5	20.7	
Sec. 28, T. 33, N. 2 E.	420	.....	60½	46.5	30.0	
Sec. 5, T. 32, N. 2 E.	500	4	61	46.5	34.4	
Sec. 10, T. 32, N. 2 E.	.....	.....	60½	46.5	.....	
Sec. 8, T. 32, N. 2 E.	530	2	60½	46.5	37.8	
Sec. 10, T. 32, N. 2 E.	241	.....	60	46.5	17.9	
Sec. 10, T. 32, N. 2 E.	400	.....	60	46.5	29.6	
Sec. 10, T. 32, N. 2 E.	360	.....	59	46.5	28.8	
Sec. 12, T. 32, N. 2 E.	300	11	59	46.5	24.0	
Sec. 14, T. 32, N. 2 E.	400	1	60	46.5	29.5	
Sec. 15, T. 32, N. 2 E.	320	.....	59	46.5	25.6	
Sec. 11, T. 32, N. 2 E.	417	.....	58	46.5	36.2	
Sec. 11, T. 32, N. 2 E.	300	.....	58½	46.5	25.0	
Sec. 13, T. 32, N. 2 E.	400	.....	59	46.5	32.0	
Sec. 24, T. 32, N. 2 E.	300	2½	59	46.5	24.0	
Sec. 25, T. 32, N. 2 E.	340	2	58	46.5	29.6	
Sec. 14, T. 32, N. 2 E.	520	.....	62½	46.5	32.5	
Sec. 7, T. 32, N. 3 E.	400	.....	61	46.5	27.6	
Sec. 8, T. 32, N. 3 E.	400	.....	60½	46.5	28.5	
Sec. 8, T. 32, N. 3 E.	300	1½	58½	46.5	25	
Sec. 9, T. 32, N. 3 E.	280	.....	59	46.5	22.4	
Sec. 15, T. 32, N. 3 E.	365	7	57	46.5	34.8	
Sec. 15, T. 32, R. 3 E.	310	Several.	60	46.5	22.9	
Sec. 15, T. 32, R. 3 E.	240	3	58	46.5	20.9	
Sec. 16, T. 32, R. 3 E.	270	4	58½	46.5	22.5	
Sec. 12, T. 32, R. 3 E.	310	8	59½	46.5	23.8	
Sec. 21, T. 32, R. 3 E.	.....	3	59½	46.5	.....	
Sec. 21, T. 32, R. 3 E.	340	1	59	46.5	27.2	
Sec. 16, T. 32, R. 3 E.	400	5	59½	46.5	30.8	
Sec. 7, T. 32, R. 3 E.	300	.....	59	46.5	24	
Sec. 21, T. 32, R. 3 E.	327	.....	55½	46.5	36.3	
Sec. 21, T. 32, R. 3 E.	310	3	55	46.5	36.5	
Sec. 14, T. 32, R. 3 E.	270	20	59¼	46.5	21.2	
Sec. 12, T. 32, R. 3 E.	250	8	57	46.5	23.8	
Sec. 23, T. 32, R. 3 E.	530	12	59	46.5	42.4	
Sec. 11, T. 32, R. 3 E.	245	11	57½	46.5	22.3	
Sec. 24, T. 32, R. 3 E.	280	.....	59	46.5	22.4	
Sec. 24, T. 32, R. 3 E.	.....	.....	63½	46.5	.....	
Sec. 24, T. 32, R. 3 E.	340	2	60	46.5	25.2	
Dixon County:						
Sec. 19, T. 32, R. 4 E.	300	2	61	[b] 48.3	23.6	
Sec. 19, T. 32, R. 4 E.	300	2	61	48.3	23.6	
Sec. 29, T. 32, R. 4 E.	280	1	61	48.3	22.0	
Sec. 29, T. 32, R. 4 E.	280	.....	60½	48.3	22.9	
Sec. 28, T. 32, R. 4 E.	290	.....	60½	48.3	24.1	
Sec. 28, T. 32, R. 4 E.	277	.....	60¾	48.3	22.1	
Sec. 28, T. 32, R. 4 E.	177	.....	59	48.3	16.5	
Sec. 34, T. 32, R. 4 E.	300	1	58	48.3	30.9	
Sec. 28, T. 32, R. 5 E.	265	.....	61	48.3	20.9	
Sec. 32, T. 32, R. 5 E.	265	3	55	48.3	39.6	
Sec. 32, T. 32, R. 5 E.	400	3	54	48.3	70.0	

[a] Yankton, S. Dak., average for 43 years.
[b] Vermilion, S. Dak., average for 16 years.

Temperatures in wells in Nebraska—Continued.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Douglas County:						
Omaha	650–800	Many.	58–62	[a] 50	.....	Many wells; large flows.
Do	664	Many.	58	50	83	
Jefferson County: Sec. 4, T. 2 N., R. 2 E.	500	Several.	70	[b] 51.9	27.7	
Knox County:						
Sec. 18, T. 33, R. 8 W.	770	Several.	70	[c] 48.1	33.8	Third flow at 740 feet.
Sec. 29, T. 31, R. 6 W.	770	14	74½	48.1	29.2	
Niobrara, mill	656	1,900	68	48.1	32.9	
Niobrara packing house	600	280	66	[c] 48.1	33.5	
Sec. 12, T. 32, R. 6 W.	548	240	65	48.1	32.4	Main flow at 520 feet.
Sec. 13, T. 33, R. 5 W.	740	900	64	48.1	[d] 37.5	Water at 600 feet.
Sec. 16, T. 33, R. 3 W.	400	8	62	48.1	28.8	
Sec. 15, T. 33, R. 3 W.	400	Few.	61	48.1	31.0	
Sec. 13, T. 33, R. 3 W.	504	2	63	48.1	33.9	
Sec. 19, T. 33, R. 3 W.	550	10	63½	48.1	35.7	
Sec. 20, T. 33, R. 3 W.	650	30	62	48.1	46.8	
Sec. 17, T. 33, R. 2 W.	400	25½	62½	48.1	27.8	
Sec. 20, T. 33, R. 2 W.	600	Few	62	48.1	43.2	Flow probably from near 400 feet.
Sec. 16, T. 33, R. 2 W.	400	11	62	48.1	28.8	
Sec. 15, T. 33, R. 2 W.	403	14	59½	48.1	35.4	
Sec. 15, T. 33, R. 2 W.	425	14	61	48.1	32.9	
Lancaster County: Lincoln Salt Lake.	2,463	Many.	60.7	[e] 50.1	[f] 57	Main flow from 600 feet. Saline water. Smaller flow from 828 feet. Test by C. A. Fisher, 1898.

[a] Average for 46 years.
[b] Fairbury average for 21 years.
[c] Santee Agency average.
[d] Calculated to 600 feet.
[e] Average for 33 years.
[f] Calculated to 600 feet.

SUMMARY.

The rates of increase indicated at Lincoln and Omaha are moderate and apparently are fairly close approximations. The many records of flowing wells in the lowlands along Missouri River in Boyd, Cedar, Dixon, and Knox counties all show high rates and in general are closely accordant. From these records lines in Plate I, showing relations to the South Dakota area, have been drawn. Most of the records show rates of increase of 1° in 22 to 30 feet, and there is a notably warm spot in the area southwest of Vermilion. Possibly some higher temperatures in some of the shallower wells are due to waters rising from lower beds, and it may be that all the high temperatures are due to this cause, if this area is a zone of permeable strata in which such a rise would be possible.

GEOLOGIC RELATIONS.

The many artesian wells in Cedar, Knox, Dixon, and Boyd counties draw their water from the Dakota sandstone, which underlies shales of Benton age and lies on Paleozoic limestone and possibly in part also in pre-Cambrian rocks. The beds are nearly horizontal

and apparently have no local disturbances or notable stratigraphic differences, so that no suggestions can be offered to account for the variations of gradient in relation to the geology. The Omaha wells penetrate deeply into Paleozoic limestone that lie nearly horizontal. The deep boring at Lincoln passed through very slightly tilted Paleozoic limestones and sandstones and reached quartzite that is supposed to be of pre-Cambrian age.

NEVADA.

COMSTOCK LODE.

The high temperatures in the deep workings of the Comstock lode near Virginia City are well known through the extended investigations of G. F. Becker.[1] The temperature at a depth of 3,100 feet was found to be 170°, indicating a rate of increase of 1° in 28 feet, and an elaborate series of temperature determinations in drill holes at various depths gave an average rate of 1° in 33 feet. The rate decreases horizontally away from the lode. It is believed that the high rate in the Comstock lode indicates the presence of hot volcanic material a few miles underground, and that ascending water is the important factor in the transportation of the heat. As a large number of data are presented, the reader interested in details should consult the monograph cited, also a critical review by Locke.[2]

TONOPAH.

Leon Dominian made measurements of underground temperatures in the Mizpah Extension, Ohio Tonopah, and Montana Tonopah shafts at Tonopah.[3] These shafts had very limited side workings and no complete ventilation. The thermometers were placed in shallow drill holes. The following results were obtained:

Temperatures (° F.) in mines at Tonopah, Nev.

Depth (feet).	Mizpah extension.	Ohio Tonopah.	Montana Tonopah.	Depth (feet).	Mizpah extension.	Ohio Tonopah.	Montana Tonopah.
100	60½	60	.....	500	69	66½	.....
200	61¾	61	.....	600	70½	69	70½
300	64	62½	.....	700	72	74	.....
317	.....	.....	64	766	.....	78	.....
400	66½	64	.....	780	73½	.....	.....
460	.....	.....	68				

The rate of increase from 100 to 780 feet in the Mizpah extension is 1° in 51.3 feet; from 100 to 760 feet in the Ohio Tonopah, 1° in 37 feet; from 317 to 600 feet in the Montana Tonopah 1° in 43.5 feet.

[1] Geology of the Comstock lode and the Washoe district: U. S. Geol. Survey Mon. 3, pp. 228-265, 1882.

[2] Locke, Augustus, The abnormal temperatures on the Comstock lode: Econ. Geology, vol. 7, pp. 583-587, 1912.

[3] Spurr, J. E., Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, pp. 263-265, 1905.

From 400 to 780 feet in the Mizpah it is 1° in 54.3 feet, and from 400 to 766 feet in the Ohio it is 1° in 26.1 feet. Spurr in comparing the Tonopah and Comstock data points out the fact that the temperature at 766 feet in the Ohio Tonopah was found in the Comstock at 900 feet, and he suggests that the increased rate toward the bottom may be due to proximity to a "local heat focus, such as a hot spring." The lack of a record of mean annual air temperature at Tonopah makes it difficult to compute the gradient. The average given by the Weather Bureau for 1916 is 48.9°. The temperature of 60° at a depth of 100 feet therefore shows a rapid increase in the upper part of the mine.

NEW JERSEY.

TEMPERATURES.

Records have been made of temperatures of flows of some of the many artesian wells along the seashore in southern New Jersey. The more useful ones are given in the following table:

Temperature in wells on coast of southern New Jersey.

Location.	Total depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temture (feet).	Remarks.
Asbury Park [a]	448	20	60	[b] 51.9	55	
Atlantic City [a]	813	105	66	[c] 52.4	59	
Longport	803	180	66	[c] 52.4	59	
Ocean Grove	420	40	60	[d] 51.9	52	
Seven Islands	408	.....	60	52.1	51	Water also at 570 and 694 feet; probably cased off.
Sea Girt	755	50	65	[e] 52	58	
Wildwood [f]	655	300	63	[g] 53.6	69	
Do [f]	1,244	10	67	[g] 53.6	[h] 88	Small flows at 625, 750, and 843 feet and salt water at 1,185 feet; probably some mixing of flows.

[a] New Jersey Geol. Survey Ann. Rept. for 1895, pp. 72–74, 1896.
[b] Average for 27 years.
[c] Average for 43 years.
[d] Asbury Park average.
[e] Asbury Park average plus 0.1°.
[f] New Jersey Geol. Survey Ann. Rept. for 1894, pp. 155–170, 1895.
[g] Cape May 32-year average minus 0.1°.
[h] Calculated to 1,185 feet.

All but the deep well at Wildwood are believed to get their flow from the bottom, so that they give a reliable indication of the rate of increase if the temperatures are correct.

Water from a 615-foot pumped well at Newark, yielding 50 gallons a minute, is reported to have a temperature of 55½°,[1] but the temperature may be modified by pumping. Mudge[2] mentions a 394-foot well at New Brunswick in which the rate of increase was found to be 1° in 72 feet.

[1] Am. Jour. Sci., 3d ser., vol. 30, p. 162, 1885.
[2] Kansas Acad. Sci. Trans., 1877–78, p. 50, 1879.

SUMMARY.

The wells on the coast of New Jersey from Asbury Park to Wildwood show rates of increase that seem closely accordant when the possible plus and minus is considered. In general there is an increase to the south from 1° in 55.3 and 52 feet at Asbury Park and Ocean Grove to 1° in 59 feet at Atlantic City and Longport and 1° in 69 feet in the 655-foot well at Wildwood.

GEOLOGIC RELATIONS.

All these wells draw their water from sands in the Coastal Plain sedimentary series,[1] which dips gently to the east and lies on a platform of pre-Cambrian crystalline rocks. The Asbury Park, Ocean City, and Sea Girt wells draw from sands in the Miocene. It would appear from these facts that there may be a lower rate in the higher beds, but the data are not sufficiently numerous or reliable to prove it.

NEW MEXICO.

Temperature determinations were made by W. T. Lee in September, 1905, in the well at Sandia siding, on the Atchison, Topeka & Santa Fe Railway, 11½ miles southwest of Isleta. A deep-well thermometer was used, with precautions to obtain accurate data. The water stood at a depth of 445 feet in the boring, which was 843 feet deep and penetrated Cretaceous shale and sandstone, overlain by sand of the Tertiary Santa Fe formation at the edge of the sheet of recent lava which covers the plateau to the north and east. The following results were obtained:

Temperatures at different depths in well at Sandia siding, N. Mex.

	°F.		°F.
843 feet	78.1	543 feet	72.1
743 feet	76.7	443 feet	71.7
643 feet	75.6		

If 54.5°, the mean annual air temperature at Los Lunas (average for 27 years), which is at about the same latitude, although 400 feet lower, is taken as a standard, the rates of increase indicated by these results are as follows:

Depth per degree of increase in temperature in well at Sandia siding, N. Mex.

	Feet.		Feet.
Surface to 843 feet	35½	Surface to 443 feet	25½
Surface to 743 feet	35	443 to 843 feet	62½
Surface to 643 feet	30½	643 to 843 feet	80
Surface to 543 feet	31	443 to 643 feet	51

The variability, especially in the amount of change from depth to depth as taken, may be due to convection, but the rate at the bottom is doubtless near the true one.

[1] Darton, N. H., Artesian prospects in the Atlantic Coastal Plain region: U. S. Geol. Survey Bull. 138, pl. 3, 1896.

NORTH CAROLINA.

No significant well temperatures have been reported from North Carolina. The water flowing from the 985-foot well at Wilmington has a temperature of 70°, or about 7° higher than the mean annual air temperature, but the flows mingle from depths of 379, 496, 578, 608, 734, and 985 feet.

NORTH DAKOTA.

Nettleton [1] has given temperatures of flows of several wells in North Dakota. The determinations were probably made with care, and as the flows come from the bottoms of the wells and most of them are of large volume the data give a close approximation of the rate of increase.

Temperatures in deep wells in North Dakota.

	Depth (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Devils Lake	1,431–1,520	82	62	[a] 36.4	56	
Ellendale	1,042–1,087	700	69	[b] 40.4	36½	
Grafton	390	700	46	[c] 37	43	
Hamilton	1,242½	Few.	41½	[d] 35.2	199	Source of flow not given.
Jamestown	1,458–1,476	460	76	[c] 39.6	40	
Oakes	937	817	62	[e] 40.9	44½	Small flows at 790, 845, and 870 feet.
Tower City	716	25	57	[f] 39.6	41	
Buffalo, 2½ miles northwest of.	600	12	52	39.6	48	
Buffalo, 6 miles northeast of.	514	25	51½	39.6	43	

[a] Average for 12 years.
[b] Fullerton average for 19 years plus 0.4°.
[c] Average for 25 years.
[d] Pembina average for 37 years.
[e] Average at Forman for 25 years.
[f] Average at Jamestown for 25 years.

These borings are in Cretaceous shale and obtain water from the Dakota sandstone, which lies on or not far above the pre-Cambrian basement. The data from the Hamilton well are doubtless inaccurate as to the depth from which the water comes, or there is a chilling of the small flow near the surface.

OHIO.

FINDLAY.

The most important data on underground temperature in Ohio are the measurements in the 2,980-foot hole at Findlay by John Johnson.[2] The hole, which was a test for oil or gas, began in the Niagara limestone and continued through older Silurian, Ordovician, and Cam-

[1] Nettleton, E. S., Final report on artesian and underflow investigations, pt. 2: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2, 1892.

[2] Johnson, John, Note on the temperature in the deep boring at Findlay, Ohio: Am. Jour. Sci., 4th ser., vol. 36, pp. 131–144, 1913; Econ. Geology, vol. 11, pp. 745–748, 1916.

brian shale, limestone, and sandstone to pre-Cambrian granite, which was penetrated 210 feet.[1] The strata have a very low dip. Johnson used six thermometers, accurately calibrated and sunk in groups of three in a special cage to prevent jarring. The principal results were as follows (averages):

Temperatures at different depths in hole at Findlay, Ohio.

	°F.		°F.
550 feet	55.6	2,650 feet	77.9
770 feet	58.1	2,800 feet	79.7
1,165 feet	67.0	3,000 feet	82.1
1,900 feet	72.5		

Some gas coming from beds at a depth of 770 feet probably vitiated the readings in that vicinity. Readings after 18 hours continuously at 100 feet gave 51.8°, which is 1.4° higher than the mean average air temperature from 27 years' observations by the United States Weather Bureau. The figures given by Johnson indicate rates of increase as follows:

Depth per degree of increase in temperature in hole at Findlay, Ohio.

	Feet.		Feet.
100 to 3,000 feet	95	1,165 to 3,000 feet	121
550 to 3,000 feet	92	1,900 to 3,000 feet	114½

MISCELLANEOUS WELLS.

Several other wells in Ohio give the following data as to rate of increase:

Temperatures in wells in Ohio.

Location.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Cuyahoga County: Cleveland	535	54	[a] 49.3	114	
Franklin County:					
Columbus	[b] 2,775½	91	[c] 52.1	71	
Do.[d]	2,575	88	52.1	71½	With Walferdin thermometer down 25 hours.
Hamilton County:					
Cincinnati [e]	1,360	60	54.3	87	
Do	1,475	61	54.3	88	
Do	1,960	63	.....	.....	No flow.
Do	2,408	62	54.3	.....	
Richland County:					
Plymouth [g]	3,020	92.8	[f] 49.4	69½	Cased to 916 feet.
	2,800	90.6	.....	68	
	1,400	71.2	.....	64	Temperature taken by Dr. R. D. Sykes.

[a] Average for 46 years.
[b] Geology of Ohio, vol. 1, p. 113; Am. Jour. Sci., 2d ser., vol. 27, p. 276, 1859.
[c] Average for 39 years.
[d] Wormley, T. E., Am. Jour. Sci., 2d ser., vol. 30, p. 306, 1860.
[e] U. S. Geol. Survey Water-Supply Paper 259, pp. 122–123, 1912.
[f] Bucyrus average for 23 years minus 0.3°.
[g] Ohio Geol. Survey Rept., vol. 6, pp. 302–303, 1888.

[1] Record given by Condit, D. D., Deep wells at Findlay, Ohio: Am. Jour. Sci., 4th ser., vol. 36, pp. 123–130, 1913.

The Cleveland well is pumped and the water in whole or part may come from higher beds. Temperatures were taken in the bottom of the old Columbus well and at 3,020, 2,800, and 1,400 feet in the Plymouth well. In the Plymouth well the rate of increase from 1,400 to 2,800 feet is 1° in 76.2 feet, and from 1,400 to 3,020 feet 1° in 70.5 feet. The strata in all these holes are limestones, sandstones, and shales dipping at low angles. The Columbus and Plymouth wells penetrated to a horizon low in the Ordovician. The Cleveland hole was sunk for water in sandstone of Devonian age.

OKLAHOMA.

TEMPERATURES.

A series of careful observations in wells and borings at several points in Oklahoma were made in 1906 by E. G. Woodruff, who used maximum thermometers lent by the Weather Bureau and lowered them to the depths given in the table. The following are the results:

Temperatures in deep wells in Oklahoma.

Location.	Depth (feet).	Temperature (° F.).	Mean annual air temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Cleveland County:					
Norman	407	65.0	60.5	90½	Old well, plugged.
Do	240	62.5	60.5	120	Pumping well.
Kay County: Newkirk, 9 miles southeast of.	760	76.0	58.7	44	Gas well, 970 feet deep. Salt water.
Lincoln County: Fallis	525	63.0	[a] 60.4	202	Old hole, full of water.
Logan County: Meridian	2,200	82.0	[b] 60.3	101½	Boring in progress.
Muskogee County:					
Muskogee	1,020	84.0	[c] 60.4	43	Old oil well.
Do	410	67.0	60.4	62	Do.
Noble County: Perry, 1 mile east of.	500	68.0	[d] 59.0	55½	Old boring.
Pawnee County:					
Cleveland	1,650	107	[e] 59.2	34½	
Do	1,625	107	59.2	34	Well shot the day before.
Ralston, 1 mile west of	2,350	128	[f] 59.2	34	In progress.
Payne County: Yale	2,500	124	59.1	38.5	Well abandoned.
Pittsburg County: McAlester, 2 miles northwest of.	540	73	[g] 63	54	In coal, diamond drill, stopped 17 hours before test.
Tulsa County:					
Red Fork, 2 miles northeast of, sec. 14.	705	78	[h] 60.3	40	Abandoned hole full of salt water; some gas.
Red Fork, sec. 15	1,170	98	60.3	31	In shale. Drilling suspended only for test.
Wagoner County: Wagoner	1,010	78	[i] 60.3	57	Small salty flow. Temperature 68°.
Washington County:					
Bartlesville	1,100	86	[j] 59.2	41	Oil well; some gas.
Owen, 2 miles northeast of.	1,275	84	[k] 50	51	Oil well; tubing just with drawn.
Ramona, 5 miles west of	1,700	103	59.4	39	Do.

[a] Guthrie average for 24 years plus 0.1°.
[b] Guthrie average.
[c] Average for 18 years.
[d] Average for 10 years.
[e] Average for 14 years.
[f] Stillwater average for 24 years.
[g] Average for 12 years.
[h] Tulsa average for 13 years.
[i] Average for 20 years.
[j] Pawhuska average plus 0.1°.
[k] Pawhuska average minus 0.1°.
[l] Pawhuska average plus 0.3°.

SUMMARY.

All the borings tested are in the northeastern part of the State except the one at McAlester, which is considerably south of the others. The results show a considerable range in the geothermal gradient, but exclusive of the pumping well at Norman, the old hole at Fallis, and the deep boring at Meridian the rate of increase is 1° in 34 to 62 feet. The boring at Meridian was in progress and may have been chilled by the pumping of cool surface water to remove the drillings. All the conditions in the Fallis well are not known, but they appeared to be favorable for a reliable test. For many of the localities there is some uncertainty as to the mean annual air temperature, which had to be approximated from stations at some distance. The holes in Pawnee and Tulsa counties and at Yale and Ramona, which show rates of 1° in 30 to 40 feet, appear to be consistent in indicating a high rate of increase for at least a portion of the central-northeastern part of the State.

GEOLOGIC RELATIONS.

The borings all penetrate limestone and shale of Carboniferous age, which dip at a low angle to the west and southwest. There are no notable local disturbances and no igneous rocks, and the pre-Cambrian rocks lie far below the surface.

PENNSYLVANIA.

ANTHRACITE REGION.

In 1909 to 1911 I made a series of careful determinations of underground temperatures in the anthracite coal fields. Thermometers were sunk in bore holes and in several places buried for a while in holes in remote chambers in coal mines. The following results were obtained:

Temperatures in coal mines in anthracite region of Pennsylvania.

Location.	Depth (feet).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Scranton, Pine Brook mine....	960	59.5	[a] 49.3	94	Bore hole 670 feet deep in mine, 290 feet below surface. Water flows. Boring suspended 18 hours.
Throop, 1 mile northeast of....	540	53.5	49.3	129	Drilling finished 24 hours.
Storrs mine, gangway, 1.C Big bed.	776	60.0	49.3	72½	Old boring 405 feet deep in mine 371 feet below ground.
Sloan mine, lowest Dunmore bed.	580	64.5	49.3	38	In new chamber in a 6-foot hole bored in coal the day before.
Woodward mine, gangway No. 5E.	1,200	61.0	[b] 49.8	107	6-foot hole in coal; no ventilation.
South Wilkes-Barre, mine, 9 slope, Baltimore bed.	1,300	64.0	49.8	91½	6-foot hole in coal; some ventilation.

[a] Average for 16 years.

[b] Scranton average plus 0.50°.

Temperature in coal mines in the anthracite region of Pennsylvania—Continued.

Location.	Depth (feet).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).	Remarks.
Dorrance mine	479	63.5	49.8	35	360-foot hole in old Baltimore workings, 119 feet below ground.
Auchincloss mine, foot of No. 3 slope, No. 1 shaft.	1,283	64.2	[a] 49.9	90	Old 115-foot hole from Ross bed to Red Ash bed.
Lackawanna & Western Coal Co., southwest of Wilkes-Barre:					
Bore hole 172	880	56.5	[b] 50	135½	Full of water.
Bore hole	843	56.0	50	140½	Do.
Bore hole, Colliery 21	1,030	61.5	50	89½	Do.
Glen Lyon drill hole near	1,598	61.5	50	130	Full of water. Thermometer down on Jan. 12, 1911, for 24 hours. Old hole.
Pottsville, Pottsville shaft, 2 miles north of.	1,596	61.8	[c] 48.3	118	Shaft full of water.
Newkirk, ¼ mile north of	1,090	59.5	48.3	90	Old drill hole in coal measures.
Minersville, near, Lehigh Valley Co.	620	54.0	48.3	109	Old bore hole with flow of water at temperature 51° F.
Do	630	54.0	48.3	110	Old bore hole containing water.
Mount Carmel, east of	1,125	56.3	48.3	141	Boring in progress; stopped 12 hours.
Mount Carmel	1,125	56.5	48.3	137	Same hole; another thermometer.
Mount Carmel, flowing well	1,125	[d] 54	48.3	197	Main flow from 1,125 feet. Some at 650 feet (end of casing). Air lift to depth of 300 feet but not working at time of test.
Mount Carmel, 2 miles east of	1,300	55.0	48.3	194	Old hole, 2,060 feet deep but blocked at 1,300 feet.
Lofty, ½ mile east of	680	[d] 51	[e] 47.0	170	1,100-foot boring blocked at 680 feet.
East Brookside	1,850	60.5	[f] 49.3	165	3-foot hole in coal in mine 1,850 feet below ground.
Tower City	415	53.0	49.3	113	Old drill hole, full of water.

[a] Scranton average plus 0.60°.
[b] Scranton average plus 0.7°.
[c] Gordon average for 13 years.
[d] By two thermometers.
[e] Approximate altitude is 1,500 feet. Mean annual may be much lower than 47°.
[f] Gordon average plus 0.1°.

An 1,800-foot diamond-drill hole bored horizontally in the coal measures by the Philadelphia & Reading Coal & Iron Co. in the Huntet tunnel, near Ashland, in Schuylkill County, found a 150-gallon flow of water with a temperature of 54°, or about 4° above the mean annual air temperature. A similar hole on Potts Run near Mahanoy City, in the same county, found a 200-gallon flow with a temperature of 51°, but the depth below the surface is not stated.

Except those in the holes in coal in the Dorrance and Sloan mines the rates of increase are remarkably low. The reasons for the differences in the others, however, are not apparent. In the holes near Scranton and Wilkes-Barre the strata are in a wide syncline with gentle dips and with a few local crenulations. In the Auchincloss mine the beds are highly tilted and faulted. The test in this mine was made in a 115-foot hole in one of the lower chambers, through which passes a ventilating current. The Glen Lyon hole and the Lehigh & Wilkes-Barre Co. bore holes are in steeply tilted strata.

The Pottsville shaft was an abandoned shaft at a mine that had been full of water for several years. This and the remaining observations in the table were made in the southern anthracite basin, where the strata lie in a deep syncline with rather steep dips on the sides.

WEST ELIZABETH.

A well 5,386 feet deep has been put down on Peters Creek about 2½ miles west of West Elizabeth and about 12 miles south-southeast of Pittsburgh. The rocks are nearly horizontal and comprise strata from those not far below the Pittsburgh coal bed to those near the base of the Devonian. Temperatures in this well were taken by William Hallock[1] in 1897, by lowering four thermometers to a depth of 5,000 feet and leaving them suspended for 16 hours. The reading was 120.9°, an increase of 68.2° over the mean annual air temperature at Pittsburgh for 46 years (52.7°), which indicates a rate of 1° to 73.3 feet. A reading at 2,350 feet gave about 78°, indicating a somewhat higher rate, but this observation was not considered satisfactory.

McDONALD.

Some preliminary information regarding a 6,975-foot hole 4 miles northwest of McDonald, 15 miles southwest of Pittsburgh, has been given by I. C. White and C. E. Van Orstrand.[2] Until recently this was the deepest hole in the United States. Precise determinations of temperature have been made by C. E. Van Orstrand, some of which are as follows:

	°F.		°F.
100 feet	57.0	4,600 feet	110.5
350 feet	59.2	5,100 feet	121.1
1,100 feet	64.4	5,600 feet	133.3
2,100 feet	76.3	6,000 feet	140.0
2,600 feet	82.4	6,600 feet	144.1
3,100 feet	88.2	6,775 feet	145.8
3,600 feet	96.8	6,975 feet	144.9
4,100 feet	104.4		

The rates of increase indicated by some of these figures are as follows:

	Feet per degree F.		Feet per degree F.
100 to 6,775 feet	75.2	3,100 to 6,775 feet	63.8
100 to 6,600 feet	75.8	4,100 to 6,775 feet	64.6
100 to 5,600 feet	72.1	5,100 to 6,775 feet	67.7
1,100 to 6,775 feet	69.7		

[1] Hallock, William, Subterranean temperatures at Wheeling, W. Va., and Pittsburgh, Pa.: School of Mines Quart., vol. 18, pp. 151–153, 1897.

[2] White, I. C., Discussion of the records of some very deep wells in the Appalachian oil fields of Pennsylvania, Ohio, and West Virginia; West Virginia: Geol. Survey, Barbour and Upshur counties, pp. xxv–lxv, 5 pls. (incl. maps), 1918.

White[1] has given five readings in this well accredited to Dr. Hallock:

Temperatures at different depths in hole near McDonald, Pa.

	°F.		°F.
525 feet	57	5,010 feet	120
2,252 feet	64	5,380 feet	127
2,397 feet	78		

The rate indicated by the temperature at 5,380 feet is 1° in 72½ feet, calculated from the mean annual air temperature at Pittsburgh, 52.7°; the difference from 525 to 5,380 feet is 1° in about 69 feet.

Mr. C. E. Van Orstrand[2] found that the temperature was 142° at a depth of 6,100 feet. With a temperature of about 55° at 100 feet the rate of increase is 1° in about 70 feet.

PITTSBURGH.

An 1,826-foot hole at the American Iron & Steel Works in the 24th ward in Pittsburgh found a strong flow of water at 1,535 to 1,606 feet with a temperature of 68°,[3] which indicates a rate of 1° in about 100 feet. The water was somewhat gassy.

HOMEWOOD.

In the Dillworth well at Homewood a series of six tests was made with the following results:[4]

Temperatures in Dillworth well, Homewood, Pa.

Depth (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).
3,600	96	83
3,710	89	
3,920	102	79½
4,002	108	72½
4,215	111	72
4,295	114	70

The tests were of only five to ten minutes duration, but exclusive of the reading at 3,710 feet, where the temperature was probably lowered by gas, the rate appears to be reasonable. The increasing rate downward is a peculiar feature.

[1] White, I. C., Petroleum and natural gas, etc.: West Virginia Geol. Survey Repts., vol. 1A, pp. 104–107, 1904.

[2] U. S. Geol. Survey Press Bull. 420, August, 1919.

[3] Pennsylvania Geol. Survey Ann. Rept. for 1886, pt. 2, pp. 733–736, 1887.

[4] British Assoc. Adv. Sci. Rept. 59th meeting, 1889, pp. 39–40.

SOUTH CAROLINA.

TEMPERATURES.

Among the few records of temperatures of flows from deep wells in South Carolina the following appear to be reliable:

Temperatures in wells in South Carolina.

	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual temperature (°F.).	Depth per degree of increase in temperature (feet).	
Charleston County.						
Charleston:						
No. 1	1,970	105	[a] 99.5	[b] 65.6	58	Cased to bottom.
No. 2	1,950	167	99	65.6	58	Do.
No. 3	1,945	695	99	65.6	58	Do.
No. 4	2,050	452	99	65.6	61	Do.
Electric Co [c]	2,001	425	99.75	65.6	[d] 57½	Cased to 1,869 feet.
Old well [e]	1,250	.....	87	65.6	58½	
Fort Moultrie [f]	1,308	10	89	65.6	56	
Do	1,920	150	[g] 98	65.6	[h] 56	Cased to 1,820 feet. Flow 1,820 to 1,900 feet.
Johns Island	500	11	70	65 6	114	Source of flow not given.
Colleton County:						
Greenpond	503	1	70	[i] 64.5	91½	Do.
Jacksonboro	420	4	72	64.5	56	Do.
Hampton County: Peeples	850	100	76	64.5	74	Do.

[a] South Carolina resources, etc., State Board of Agriculture, p. 674, 1883.
[b] Average for 46 years.
[c] Stephenson, L. W., A deep well at Charleston, S. C.: U. S. Geol. Survey Prof. Paper 90, p. 70, 1914. Temperature by I. N. Knapp, engineer.
[d] Calculated to 1,971 feet.
[e] Am. Jour. Sci., 2d ser., vol. 47, p. 357, 1869.
[f] U. S. Geol. Survey Water-Supply Paper 114, p. 151, 1905.
[g] U. S. Geol. Survey Bull. 298, p. 265, 1906.
[h] Calculated to 1,820 feet.
[i] Yemassee average for 23 years.

SUMMARY.

As the Charleston wells are cased to or nearly to the bottom, presumably the others are also. The temperatures are probably reliable, especially those of the Charleston wells. The new well at the electric-light plant is cased to a depth of 1,869 feet, and the flow comes from a bed extending from 1,971 to 1,999 feet. The results of the Charleston and Fort Moultrie wells are fairly accordant and give an average rate of 1° in about 60 feet. It is possible that the lower rates indicated by the wells at Greenpond and Johns Island are due to ingress of water above the bottoms of the borings.

GEOLOGIC RELATIONS.

These wells all penetrate clays, sands, and gravels of the thick wedge of Tertiary and Cretaceous strata constituting the Coastal Plain. These strata dip very gently eastward and lie on an eastward sloping floor of old crystalline rocks. The Charleston wells reach the basal beds of the Black Creek formation, which is low in the Upper Cretaceous; the other holes in the list reach sands of Eocene age.

SOUTH DAKOTA.

TEMPERATURES.

In the course of detailed investigations of the geology and water resources of parts of South Dakota I and my associates have observed many underground temperatures, mainly of the flow of artesian wells. Some carefully determined temperatures of representative wells have been recorded by Sheppard,[1] and several tests were made by Nettleton.[2] Records of wells at Belle Fourche, Cheyenne Agency, and Edgemont were obtained from correspondents. A large number of data were obtained by J. E. Todd [3] in field work for geologic folios and reports on the artesian area in Beadle, Brown, Edmunds, Faulk, Hand, and Spink counties, in the eastern part of the State. His observations were made with instruments that had been verified in Washington. No flow was tested unless it was believed to be of sufficient volume to give a closely approximate indication of the temperature at the bottom.

Temperatures in wells in South Dakota.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
Aurora County:					
Plankington	740	225	[a] 62	[b] 45.5	44.8
White Lake	850	150	[a] 64	[b] 45.5	45.9
Beadle County:					
Huron	960	2,250	70	[c] 43.3	35.9
Do	836	360	65	43.3	38.5
Wolsey	858–878	330	[a] 76	43.3	26.2
SE. ¼ sec. 8, T. 113, R. 65	950	.....	[d] 70.6	[e] 43	34.4
SE. ¼ sec. 11, T. 113, R. 65	971	.....	[d] 71.5	43.3	34.1
NE. ¼ sec. 1, T. 113, R. 65	950	.....	[d] 71.5	43.3	33.3
SW. ¼ sec. 14, T. 113, R. 65	955	.....	[d] 72.5	43.3	32.4
SW. ¼ sec. 30, T. 113, R. 64	980	20	[d] 71.5	43.3	34.4
SW. ¼ sec. 28, T. 113, R. 64	880	.....	[d] 75	43.3	27.5
NE. ¼ sec. 11, T. 113, R. 64	925+	.....	[d] 71.5	43.3	32.5
NE. ¼ sec. 21, T. 113, R. 63	800	200	[d] 66	43.3	34.8
T. 113, R. 63	988	30	[d] 67.5	43.3	40.3
NE. ¼ sec. 23, T. 113, R. 63	860–888	.....	[d] 67.7	43.3	34.8
SW. ¼ sec. 31, T. 113, R. 62	815	120	[d] 64.4	43.3	38.1
NE. ¼ sec. 19, T. 113, R. 61	148	50	[d] 48	43.3	29.6
SE. ¼ sec. 5, T. 113, R. 61	766	.....	[d] 62.5	43.3	39.3
SW. ¼ sec. 9, T. 113, R. 60	810	25	[d] 63.3	43.3	40
T. 112, R. 65	1,005	40	[d] 77.2	43.3	29.6
NE. ¼ sec. 14, T. 112, R. 63	600	.....	[d] 58.3	43.3	40
NW. ¼ sec. 7, T. 112, R. 62	793	.....	[d] 66.7	43.3	33

[a] Nettleton, observer.
[b] Mitchell average for 23 years.
[c] Average from 1882 to 1908. It is 42.1° from 1882 to 1916 or 0.4° colder than Redfield, 35 miles farther south.
[d] J. E. Todd, observer.
[e] Redfield average plus 0.1°.

[1] Sheppard, J. H., South Dakota Agr. College Bull. 41, 35 pp., 1894.

[2] Nettleton, E. S., Artesian and underflow investigations: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 4, 1893.

[3] U. S. Geol. Survey Geol. Atlas, folios 96, 97, 99, 113, 114, 156, 165; Geology and water resources of part of the lower James River valley: U. S. Geol. Survey Water-Supply Paper 90, 47 pp., 23 pls., 1904.

Temperatures in wells in South Dakota—Continued.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
Beadle County—Continued.					
SW. ¼ sec. 2, T. 112, R. 62	774	40	a 65	43.3	35.6
Center sec. 13, T. 112, R. 63	825	.....	a 66.7	43.3	35.2
SW. ¼ sec. 7, T. 112, R. 61	704	.....	a 63.8	43.3	34.3
NE. ¼ sec. 8, T. 112, R. 61	764	35	a 62.8	43.3	39.1
Hitchcock	950	.....	b 71.5	43.3	33.6
Do	953	1,260	70.1	43.3	31.8
Bonhomme County:					
Tyndall	815	700	b 62.6	c 47.3	53.3
Do	815	700	d 62	e 47.3	55.4
Springfield	530–592	3,290	d 65	47	29.4
Sec. 19, T. 94, R. 58	578	.....	d 60	.....	.....
Sec. 34, T. 95, R. 59	734	.....	d 61	.....	.....
Sec. 31, T. 94, R. 58	645	.....	d 62	.....	.....
Sec. 5, T. 93, R. 58	665	.....	d 62	.....	.....
Sec. 1, T. 93, R. 59	646	.....	d 62	.....	.....
Brown County:					
Frederick	1,045–1,139	135	d 69	f 41	37.3
Westport	1,000	.....	b 66.2	g 41.5	40.5
Columbia	927–964	940	d 63	h 41.6	43.3
Groton, 4 miles north of	840–942	150	d 63	i 42	40.0
Aberdeen, City well 1	1,077–1,100	400	b 66.9	j 41.9	43.1
Do	1,004,918	.....	d 66	41.9	44.7
NE. ¼ sec. 10, T. 123 R. 65	1,000	120	a 65	41.9	43.3
SE. ¼ sec. 10, T. 123 R. 65	1,000	.....	a 64	41.9	45.2
SE. ¼ sec. 12, T. 123 R. 65	980	25	a 65	41.9	42.4
S ½ sec. 30, T. 123 R. 65	1,000+	.....	a 65	41.9	43.3
NE. ¼ sec. 32, T. 123 R. 65	1,020	.....	a 65.5	41.9	42.2
NW. ¼ sec. 15, T. 123 R. 64	800	.....	a 60	41.9	44.2
SE. ¼ sec. 27, T. 123 R. 60	875–920	105	a 63	k 41.9	41.4
Sec. 8, T. 123, R. 60	977	105	d 62	42	48.6
SW. ¼ sec. 11, T. 122 R. 65	1,075	.....	b 66	42	44.8
South center of sec. 22, T. 122, R. 65	1,070	37	b 65	42	46.5
NW. ¼ sec. 19, T. 122, R. 64	931	50	b 64	42	42.3
SE. ¼ sec. 21, T. 122, R. 63	900–1,000	a 34	l 67	42	36
SE. ¼ sec. 30, T. 121, R. 64	945	.....	l 75	m 42.1	28.7
SE. ¼ sec. 17, T. 121, R. 64	300–340	.....	a 52	42.1	30
NE. ¼ sec. 2, T. 122, R. 61	915	70	a 64	42.1	41.4
SW. ¼ sec. 32, T. 122, R. 60	940	76	a 67	42.1	42.9
NE. ¼ sec. 27, T. 121, R. 61	894	14	a 67	42.1	40.7
NW. ¼ sec. 27, T. 121, R. 61	920	43	a 67	42.1	42
SW. ¼ sec. 33, T. 121, R. 61	900	.....	a 66.5	42.1	36.9
NW. ¼ sec. 34, T. 121, R. 61	910	.....	a 69+	42.1	33.8
Brule County:					
Chamberlain	585–600	4,000	b 71.6	45	22
Do	785	530	74	45	27
Kimball	988–1,068	185	b 66.9	44	43.2
Chamberlain, 25 miles southeast of	851–937	1,000	b 70	n 45.5	34.7
NW. ¼ sec. 30, T. 101, R. 68	800,900	80	80	45.5	23.2
Buffalo County:					
Crow Creek	760–780	Many.	72	45	28.1
Butte County:					
Belle Fourche	515	100	o 54	44	51.5
Do	323	Many.	o 48	45.5	80.6
Orman	1,417	600	p 94	45.5	28.3

a J. E. Todd, observer.
b J. H. Sheppard, observer.
c Average for 20 years.
d E. S. Nettleton, observer.
e Yankton average plus 0.5°.
f Aberdeen average for 27 years minus 0.9°.
g Aberdeen average minus 0.4°.
h Aberdeen average minus 0.3°.
i Aberdeen average plus 0.1°.
j Mean for 27 years.
k Aberdeen average plus 0.1°.
l Doubtful.
m Aberdeen average plus 0.2°.
n Approximated.
o F. A. Durst, observer.
p U. S. Geol. Survey Water-Supply Paper 227, p. 77, 1909.

Temperatures in wells in South Dakota—Continued.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
Charles Mix County:					
Greenwood	651	3,000	70	48.9	30.9
Lake Andes	725–773	1,500	70	46	30.2
Do	802	Many.	70	46	33.4
Sec. 17, T. 98, R. 66	860	Many.	70	[a] 45	34.4
Sec. 33, T. 99, R. 66	840	20	70	45	33.6
Custer County:					
Buffalo Gap	725	No flow.	[b] 65½	[c] 45	37
Davison County:					
Mitchell	530	600	[d] 56	[e] 45.5	50.5
Sec. 3, T. 101, R. 62	565	60	[f] 56	[g] 45.5	54.8
Sec. 35, T. 104, R. 60	507	40	56	[e] 45.5	48.3
Day County: Andover	1,070	300	[h] 71.6	[a] 42	39.3
Dewey County: Cheyenne Agency	1,337	500	79	[i] 43.8	35.1
Douglas County:					
Armour	696–757	1,500	[h] 68.3	[j] 46.4	31.8
Armour, 3 miles south of	703–736	.....	65	46.4	37.8
Edmunds County:					
Ipswich	1,265	Many.	[h] 71.6	[k] 42	[l] 42.7
SE. ¼ sec. 22, T. 123, R. 68	1,195	97	73	42	38.6
SE. ¼ sec. 23, T. 123, R. 68	1,125	.....	[f] 70.5	[m] 42.2	39.8
SE. ¼ sec. 8, T. 123, R. 67	1,140	.....	[f] 63	[m] 42.2	54.8
NW. ¼ sec. 10, T. 123, R. 67	1,185	.....	[f] 69	[m] 42.2	44.2
SW. ¼ sec. 10, T. 123, R. 67	1,115	.....	[f] 69	[m] 42.2	41.6
SW. ¼ sec. 11, T. 123, R. 67	1,135	.....	[f] 68	[m] 42.2	44.
NW. ¼ sec. 20, T. 123, R. 67	1,140–1,160	.....	[f] 69.5	[m] 42.2	41.8
SW. ¼ sec. 23, T. 123, R. 67	1,140	.....	[f] 67	[m] 42.2	46.
NE. ¼ sec. 33, T. 123, R. 67	1,078	.....	[f] 67	[m] 42.2	43.5
Center of sec. 8, T. 123, R. 66	1,100	.....	[f] 66	[m] 42.2	46.2
SE. ¼ sec. 20, T. 123, R. 66	1,050–1,100	.....	[f] 69.5	[m] 42.2	38.5
NW. ¼ sec. 16, T. 122, R. 67	1,140	.....	[f] 65.5	[m] 42.2	48.9
SE. ¼ sec. 26, T. 122, R. 67	1,000–1,060	.....	[f] 65	[m] 42.2	43.[illegible]
SE. ¼ sec. 4, T. 122, R. 66	1,080	.....	[f] 65.5	[m] 42.2	46.8
SW. ¼ sec. 10, T. 122, R. 66	1,025–1,070	.....	[f] 65.5	[m] 42.2	45.
NE. ¼ sec. 19, T. 122, R. 66	1,038	.....	[f] 66.5	[m] 42.2	44.5
NE. ¼ sec. 29, T. 122, R. 66	1,007–1,045	.....	[f] 65	[m] 42.2	43.7
SE. ¼ sec. 30, T. 122, R. 66	1,050	.....	[f] 65.5	[m] 42.2	45.1
SE. ¼ sec. 32, T. 122, R. 66	1,060	.....	[f] 67.5	[m] 42.2	41.9
SE. ¼ sec. 33, T. 122, R. 66	1,030	.....	[f] 66	[m] 42.2	42.9
SE. ¼ sec. 8, T. 121, R. 67	1,050+	.....	[f] 64	[n] 42	47.8
NW. ¼ sec. 32, T. 121, R. 67	1,125	.....	[f] 66	[n] 42	46.8
SE. ¼ sec. 26, T. 121, R. 67	1,155	.....	[f] 65	[n] 42	50.2
SW. ¼ sec. 10, T. 121, R. 66	1,000	.....	[f] 65	[n] 42	43.5
SE. ¼ sec. 29, T. 121, R. 66	1,000	.....	[f] 64.5	[n] 42	44.4
NE. ¼ sec. 32, T. 121, R. 66	967	.....	[f] 64	[n] 42	44.
Fall River County: Edgemont	2,920–2,965	350	[o] 122	[p] 46	39
Faulk County:					
SE. ¼ sec. 13, T. 120, R. 68	1,125	25	[f] 66	[q] 42.7	48.2
NE. ¼ sec. 19, T. 120, R. 67	1,140	Many.	[f] 68	[q] 42.7	45
SE. ¼ sec. 21, T. 120, R. 67	1,040±	Many.	[f] 67	[q] 42.7	42.8
SW. ¼ sec. 1, T. 120, R. 67	1,085–1,120	Many.	[f] 66	[q] 42.7	46.5
SE. ¼ sec. 26, T. 120, R. 67	1,050	Many.	[f] 69.5	[q] 42.7	39.1
NW. ¼ sec. 24, T. 120, R. 67	1,038	35	[f] 67+	[q] 42.7	42.7
NW. ¼ sec. 6, T. 120, R. 66	1,066	100	[f] 67.5	[q] 42.7	42.9
SW. ¼ sec. 2, T. 120, R. 66	1,001	65	[f] 66.3	[q] 42.7	42.4
NE. ¼ sec. 26, T. 120, R. 66	965	Many.	[f] 65.5	[q] 42.7	42.3

[a] Approximated.
[b] N. H. Darton, observer, with deep-well thermometer.
[c] Oelrichs average for 25 years minus 0.2°.
[d] E. S. Nettleton, observer.
[e] Average for 23 years.
[f] J. E. Todd, observer.
[g] Mitchell average plus 0.2°.
[h] J. H. Sheppard, observer.
[i] Pierre average for 26 years minus 1.7°.
[j] Average for 22 years.
[k] Bowdle average for 14 years minus 0.2°.
[l] Flow from 1,195 feet.
[m] Bowdle average.
[n] Bowdle average minus 0.2°
[o] Taken by engineer with Darton thermometer; varied from 121° to 122°.
[p] Oelrichs average, minus 0.2°.
[q] Faulkton average for 22 years minus 0.2°.

Temperatures in wells in South Dakota—Continued.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
Faulk County—Continued.					
SW. ¼ sec. 1, T. 119, R. 67	980	Many.	[a] 69	[b] 42.8	37.4
SW. ¼ sec. 9, T. 119, R. 67	1,050	Many.	[a] 69.5	[b] 42.8	39.3
North center of sec. 15, T. 119, R. 67	1,060	Many.	[a] 68	[b] 42.8	42.1
SW. ¼ sec. 18, T. 119, R. 67	1,257	Many.	[a] 71	[b] 42.8	44.5
SW. ¼ sec. 17, T. 119, R. 67	1,120	Many.	[a] 69	[b] 42.8	42.7
SW. ¼ sec. 21, T. 119, R. 67	1,050	Many.	[a] 65	[b] 42.8	47.3
SW. ¼ sec. 24, T. 119, R. 67	1,162	Many.	[a] 69+	[b] 42.8	44.3
SE. ¼ sec. 25, T. 119, R. 67	1,031	20	[a] 69	[b] 42.8	39.3
SW. ¼ sec. 25, T. 119, R. 67	1,035	.....	[a] 68	[b] 42.8	41
NW. ¼ sec. 30, T. 119 R. 67	1,000	.....	[a] 70	[b] 42.8	36.7
NE. ¼ sec. 31, T. 119, R. 67	910	.....	[a] 70	[b] 42.8	33.4
NE. ¼ sec. 34, T. 119, R. 67	950	.....	[a] 67	[b] 42.8	39.2
SE. ¼ sec. 9, T. 119, R. 66	988	50±	[a] 66	[b] 42.8	42.6
NW. ¼ sec. 15, T. 119, R. 66	1,010	50	[a] 66	[b] 42.8	43.5
NW. ¼ sec. 20, T. 119, R. 66	1,002	50	[a] 67	[b] 42.8	41.4
SE. ¼ sec. 23, T. 119, R. 66	1,020	50	[a] 64	[b] 42	48.1
Faulkton	1,032±	100	[c] 74.5	[d] 42.9	32.6
SE. ¼ sec. 24, T. 118, R. 68	1,050+	80	[a] 69	[d] 42.9	40.2
SE. ¼ sec. 18, T. 118, R. 67	1,067	75	[a] 71	[d] 42.9	38
NW. ¼ sec. 20, T. 118, R. 67	1,020	.....	[a] 66.5	[d] 42.9	42.2
NW. ¼ sec. 28, T. 118, R. 67	1,029	75	[a] 69	[d] 42.9	39.4
West center of sec. 22, T. 118, R. 67	1,010	70	[a] 69	[d] 42.9	38.7
SW. ¼ sec. 13, T. 118, R. 67	1,002	60	[a] 69	[d] 42.9	38.4
SW. ¼ sec. 34, T. 118, R. 67	980	Many.	[a] 67.8	[d] 42.9	39.3
NW. ¼ sec. 15, T. 118, R. 66	1,029	Many.	[a] 68.5	[d] 42.9	40.1
NW. ¼ sec. 25, T. 118, R. 66	972	Many.	[a] 67.3	[d] 42.9	39.8
SW. ¼ sec. 31, T. 117, T. 68	1,095	90	[a] 68.8	[e] 43	42.4
Miranda	1,095	Many.	[a] 68.3	[e] 43	43.3
Center of sec. 31, T. 117, R. 67	1,010	Many.	[a] 69.6	[e] 43	38
SW. ¼ sec. 6, T. 117, R. 67	1,095	Many.	[a] 68.8	[e] 43	42.4
NE. ¼ sec. 31, T. 117, R. 66	1,030	Many.	[a] 69.6	[e] 43	38.7
Rockham	1,010	.....	[a] 69.6	[e] 43	38
SE. ¼ sec. 11, T. 117, R. 66	913	45	[a] 66.7	[e] 43	38.5
Twin Lakes	1,085	.....	[a] 65.6	[e] 43	48
Orient	1,215	90	[a] 75	[e] 43	38
Gregory County: Fort Randall	576	600	[f] 80	47	17.5
Hand County:					
Miller	1,115–1,139	360	[c] 79.8–[f] 78	[g] 44.0	31.2
Miller, near	1,105	.....	[a] 76	[g] 44.0	34.6
Do	1,100	.....	[a] 78.9	[g] 44.0	31.5
Do	1,100	200	[a] 78.5	[g] 44.0	31.9
NE. ¼ sec. 10, T. 116, R. 66	951	.....	[a] 73	[h] 43.1	31.8
NE. ¼ sec. 7, T. 115, R. 68	1,150	Many.	[a] 74	[h] 43.1	37.2
SE. ¼ sec. 22, T. 115, R. 68	1,065	Many.	[a] 74.5	[h] 43.1	33.9
SE. ¼ sec. 12, T. 115, R. 67	955	.....	[a] 71	[h] 43.1	34.2
NE. ¼ sec. 22, T. 114, R. 66	880	42	[a] 68.6	[i] 43.3	34.4
NE. ¼ sec. 12, T. 113, R. 68	1,040	Many.	[a] 78.9	[j] 43.5	29.4
SE. ¼ sec. 3, T. 113, R. 67	1,008	60	[a] 71.5	[j] 43.8	36.4
SE. ¼ sec. 18, T. 113, R. 66	1,105	40	[a] 76.5	[j] 43.8	33.8
SE. ¼ sec. 25, T. 113, R. 67	1,100–1,129	400	[a] 78.5	[j] 43.8	31.7
NW. ¼ sec. 22, T. 113, R. 66	967	.....	[a] 73.5	[j] 43.8	32.6
NW. ¼ sec. 31, T. 113, R. 67	1,099–1,133	.....	[a] 78.5	[j] 43.8	31.7
SE. ¼ sec. 3, T. 112, R. 68	1,100	110	[a] 78.9	[k] 43.8	31.6
NW. ¼ sec. 5, T. 112, R. 67	1,165	14	[a] 76	[h] 44	36.3
SE. ¼ sec. 4, T. 112, R. 67	1,165	50	[a] 76.6	[h] 44.0	33.1
NE. ¼ sec. 2, T. 112, R. 66	892	40	[a] 75.7	[h] 44.0	28.4
Hughes County:					
Pierre	[l] 1,215–1,245	200	[a] 89	[m] 45.5	27.9
East Pierre	1,150–1,170	900	[c] 91.8	45.5	24.8
Harold	1,435–1,451	84	[c] 94.9	45	28.7

[a] J. E. Todd, observer.
[b] Faulkton average for 22 years minus 0.1°.
[c] J. H. Sheppard, observer.
[d] Average for 22 years.
[e] Faulkton average plus 0.1°.
[f] E. S. Nettleton, observer.
[g] Highmore average for 26 years minus 0.6°.
[h] Howell average for 15 years.
[i] Howell average plus 0.2°.
[j] Howell average plus 0.4°.
[k] Howell average plus 0.7°.
[l] Other flows 1,140 and 1,185 feet; much gas.
[m] Average for 26 years.

Temperatures in wells in South Dakota—Continued.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
Hutchinson County: Tripp	824	700	63	[a] 46	48.5
Hyde County: Highmore	1,537–1,552	14	72	[b] 44.6	56
Jerauld County: Alpena City well	749, 785	500	75.0	[c] 42.3	22.9
Kingsbury County: Iroquois	855	1,000	[d e] 71.4	[f] 42.1	29.2
Lyman County: Kennebec	1,301	50	96±	[g] 45.5	25.8
Marshall County: Britton	967–1,000	600	[h] 64	[i] 41.4	43.2
Sanborn County:					
Letcher	577	80	[h] 58	[j] 44.6	43.1
Woonsocket, mill	684–725	1,150	[d] 61.5	[k] 44.4	40
Woonsocket, Hines	689–742	.....	[h] 65	44.4	34.3
SE. ¼ sec. 33, T. 105, R. 60	425	165	58	[j] 44.6	31.7
Spink County:					
South center of sec. 6, T. 120, R. 65	990	278	[l] 65.5	[m] 43.4	44.8
NE. ¼ sec. 7, T. 120, R. 64	948	100	[l] 65.7	43.4	42.5
North center of sec. 29, T. 120, R. 64	912	84	[l] 64.5	43.4	43.2
SW. ¼ sec. 30, T. 120, R. 63	908	.....	[n] 70	43.4	34.1
SW. ¼ sec. 32, T. 120, R. 63	920	180	[n] 65.5	43.4	41.6
NW. ¼ sec. 33, T. 120, R. 63	960	.....	[n] 67	43.4	40.7
NW. ¼ sec. 27, T. 120, R. 63	913	.....	[n] 66	43.4	40.4
NW. ¼ sec. 3, T. 120, R. 63	904	.....	[n] 64	43.4	43.9
SE. ¼ sec. 1, T. 120, R. 63	842	.....	[n] 65	43.4	39
SW. ¼ sec. 13, T. 120, R. 63	920	.....	[n] 67	43.4	38.9
Sec. 13, T. 120, R. 63	900	.....	[n] 64	43.4	43.7
SW. ¼ sec. 14, T. 120, R. 62	925	.....	[n] 67.5	43.4	38.4
SE. ¼ sec. 14, T. 120, R. 62	914	.....	[n] 68	43.4	37.1
SW. ¼ sec. 13, T. 120, R. 62	914	.....	[n] 68	43.4	37.1
NE. ¼ sec. 9, T. 120, R. 61	900	40	[n] 68.2	43.4	36.3
SW. ¼ sec. 15, T. 120, R. 61	880	.....	[n] 66.5	43.4	38.1
SW. ¼ sec. 21, T. 120, R. 61	884	.....	[n] 66	43.4	39.1
NE. ¼ sec. 23, T. 120, R. 61	980	.....	[n] 68	43.4	39.8
NE. ¼ sec. 34, T. 120, R. 61	900	.....	[n] 65	43.4	41.6
NW. ¼ sec. 28, T. 120, R. 60	1,000	Many.	[n] 69	43.4	39
NW. ¼ sec. 2, T. 119, R. 62	912	40	[n] 66	43.4	40.3
SW. ¼ sec. 25, T. 119, R. 62	907	.....	[n] 66	43.4	40.1
NE. ¼ sec. 15, T. 119, R. 63	948	45	[n] 67.5	43.4	39.3
SE. ¼ sec. 28, T. 119, R. 63	925	.....	[n] 65	43.4	42.8
NW. ¼ sec. 32, T. 119, R. 64	842	.....	[n] 64	43.4	46
SE. ¼ sec. 3, T. 119, R. 60	1,000	Many.	[n] 68	43.4	40.6
Mellette	920	1,320	[e] 65	[o] 43.4	42.6
Brown well	925	.....	[e] 65	43.4	42.8
Baker well	920	.....	[e] 65	43.4	42.6
Day well	915	.....	[e] 65	43.4	42.3
Bird well	930	.....	[e] 65	43.4	43
NE. ¼ sec. 31, T. 119, R. 61	964	60	[n] 67.5	43.4	40
SE. ¼ sec. 29, T. 119, R. 61	896	.....	[n] 68.0	43.4	36.4
SE. ¼ sec. 3, T. 119, R. 60	1,000	.....	[n] 68.5	43.4	40
SW. ¼ sec. 30, T. 118, R. 65	939	.....	[n] 64.0	43.4	45.6
SW. ¼ sec. 18, T. 118, R. 65	940	80	[n] 67.5	43.4	39
SW. ¼ sec. 3, T. 118, R. 63	927	.....	[n] 63.0	43.4	47.2
SW. ¼ sec. 10, T. 118, R. 65	1,032	.....	[n] 67	43.4	43.7
NE. ¼ sec. 32, T. 118, R. 64	960	160	[n] 64.4	43.4	45.7
SW. ¼ sec. 10, T. 118, R. 63	895	.....	[n] 62.5	43.4	46.8
SE. ¼ sec. 11, T. 118, R. 65	930	.....	[n] 65.0	43.4	43
NE. ¼ sec. 20, T. 118, R. 63	893	.....	[n] 62	43.4	48
Northville	980	1,900	[d] 66.1	43.4	43.1
SW. ¼ sec. 24, T. 118, R. 63	954	.....	[n] 64	43.4	46.3
NE. ¼ sec. 30, T. 118, R. 63	976	200	[n] 69	43.4	38.1
Center of sec. 2, T. 118, R. 62	920	25	[n] 67	43.4	39
Turton	850	1,300	[n] 67	43.4	36
NW. ¼ sec. 15, T. 118, R. 60	943	25	[n] 68	43.4	38.3
NW. ¼ sec. 10, T. 118, R. 60	986	35	[n] 64.5	43.4	46.7
NE. ¼ sec. 26, T. 118, R. 60	985	.....	[n] 68.5	43.4	39.2
SW. ¼ sec. 35, T. 117, R. 65	967	65	[n] 67.7	43.4	39.8
SW. ¼ sec. 20, T. 117, R. 64	955	.....	[n] 66.7	43.4	41
NE. ¼ sec. 29, T. 117, R. 64	951	.....	[n] 66.7	43.4	40.8

[a] Menno average for 26 years minus 0.5°.
[b] Average for 26 years; flow small.
[c] Huron average plus 0.2°.
[d] J. H. Sheppard, observer.
[e] E. S. Nettleton gives 72.0°.
[f] Huron average.
[g] Average for 16 years.
[h] E. S. Nettleton, observer.
[i] Aberdeen average minus 0.5°.
[j] Forestburg average plus 0.2°.
[k] Forestburg average for 25 years.
[l] Other flows 1,140 and 1,185 feet; much gas.
[m] Mellette average for 22 years.
[n] J. E. Todd, observer.
[o] Average for 22 years.

Temperatures in wells in South Dakota—Continued.

Location.	Depth of main flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Mean annual temperature (° F.).	Depth per degree of increase in temperature (feet).
SW. ¼ sec. 31, T. 117, R. 63	866	45	[a] 66.7	[b] 42.9	36.4
East center of sec. 7, T. 117, R. 63	972–1,020	.....	[a] 68.7	42.9	37.3
NW. ¼ sec. 32, T. 117, R. 62	810	300	[a] 64.4	42.9	37.7
SE. ¼ sec. 27, T. 117, R. 61	900	110	[a] 62.2	42.9	46.6
Doland	895	370	[c] 69	42.9	34.2
NW. ¼ sec. 33, T. 116, R. 65	900	120	[a] 67.2	42.9	37
SE. ¼ sec. 13, T. 116, R. 65	890	.....	[a] 66.7	42.9	37.4
Redfield	964	1,260	[c] 70.1	42.9	35.4
Redfield, south end	920	.....	[a] 70.1	42.9	33.8
Redfield	944	.....	[a] 71.7	42.9	32.8
NE. ¼ sec. 35, T. 116, R. 64	949	.....	[a] 64.4	42.9	44.1
NW. ¼ sec. 31, T. 116, R. 64	912	.....	[a] 66.7	42.9	38.3
SE. ¼ sec. 9, T. 116, R. 63	851	150	[a] 62.2	42.9	44.1
East center of sec. 35, T. 116, R. 63	900	.....	[a] 64.2	42.9	42.3
East center of sec. 25, T. 116, R. 63	880	.....	[a] 62.2	42.9	45.6
SW. ¼ sec. 4, T. 116, R. 62	875	50	[a] 64.5	42.9	40.5
South center of sec. 34, T. 116, R. 61	915	.....	[a] 62.5	42.9	46.7
SE. ¼ sec. 13, T. 115, R. 64	942	.....	[a] 64.4	[d] 43	45
NW. ¼ sec. 9, T. 115, R. 64	930	.....	[a] 65.2	[e] 42.9	41.7
SW. ¼ sec. 10, T. 115, R. 64	935	.....	[a] 65.4	42.9	41.5
SW. ¼ sec. 33, T. 115, R. 63	867	.....	[a] 65.4	42.9	38.5
SE. ¼ sec. 1, T. 115, R. 63	988	.....	[a] 62.2	42.9	51.2
NW. ¼ sec. 29, T. 115, R. 62	936	.....	[a] 64.5	42.9	43.3
NE. ¼ sec. 22, T. 115, R. 61	885	75	[a] 62.5	42.9	45.2
NE. ¼ sec. 23, T. 115, R. 61	885	75	[a] 65.3	42.9	39.6
NW. ¼ sec. 27, T. 115, R. 61	450	.....	[a] 56.2	42.9	33.8
West center of sec. 6, T. 115, R. 60	940	20	[a] 66.7	42.9	39.5
SW. ¼ sec. 9, T. 115, R. 60	886	.....	[a] 67.7	42.9	35.7
SE. ¼ sec. 3, T. 115, R. 60	900	.....	[a] 67.0	42.9	37.3
Glidden, sec. 32, T. 114, R. 63	1,973	550	[a] 70.1	42.9	35.7
NE. ¼ sec. 29, T. 114, R. 65	1,029	35	[a] 71.5	42.9	36
NE. ¼ sec. 30, T. 114, R. 62	840	200	[a] 67.0	42.9	34.8
SW. ¼ sec. 5, T. 114, R. 62	835	.....	[a] 64.5	42.9	38.6
SW. ¼ sec. 7, T. 114, R. 61	770	25	[a] 62.2	42.9	40.2
NW. ¼ sec. 19, T. 114, R. 61	800	.....	[a] 66.7	42.9	33.6
SW. ¼ sec. 27, T. 114, R. 61	744	.....	[a] 64.4	42.9	34.6
NE. ¼ sec. 23, T. 114, R. 61	790	.....	[a] 65.4	42.9	35.1
West center of sec. 28, T. 114, R. 61	735	.....	[a] 65.3	42.9	32.8
NW. ¼ sec. 11, T. 114, R. 60	884	.....	[a] 69.6	42.9	33.1
SE. ¼ sec. 18, T. 114, R. 60	860	.....	[a] 63.7	42.9	33.3
SE. ¼ sec. 17, T. 114, R. 60	848	.....	[a] 67	42.9	35.2
NE. ¼ sec. 23, T. 114, R. 60	835	.....	[a] 67.5	42.9	33.9
SW. ¼ sec. 27, T. 114, R. 60	850	30	[a] 62.2	42.9	44
Todd County: Rosebud Agency, 18 miles northeast of [f]	2,500	No.	153½	[g] 46.9	23.5
Yankton County: [h]					
Yankton	489–595	1,450	[i] 62	[j] 46.5	31.5
Do	432–455	330	[i] 60	46.5	32
Do	610–615	880	[i] 62	46.5	39.3
Yankton Asylum	600–672	165	[i] 64	46.5	34.3
Yankton cement works	450–500	1,300	[i] 64	46.5	24.3
Sec. 12, T. 93, R. 56	375	8	[a] 60	46.5	27.8
Sec. 11, T. 93, R. 56	380	12	[a] 60	46.5	28.2
Sec. 19, T. 93, R. 56	400	25	[a] 60	46.5	29.6

[a] J. E. Todd, observer.
[b] Redfield average for 19 years.
[c] J. H. Sheppard, observer. Nettleton gives 64° for flows from both wells.
[d] Redfield average plus 0.1°.
[e] Redfield average.
[f] Darton thermometer sunk to bottom.
[g] Average at Cutmeat for 23 years.
[h] 51st Cong., 1st sess., S. Ex. Doc. 222, p. 115, 1890; Artesian and underflow investigation: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2, p. 65, 1892.
[i] E. S. Nettleton, observer.
[j] Average for 27 years.

SUMMARY.

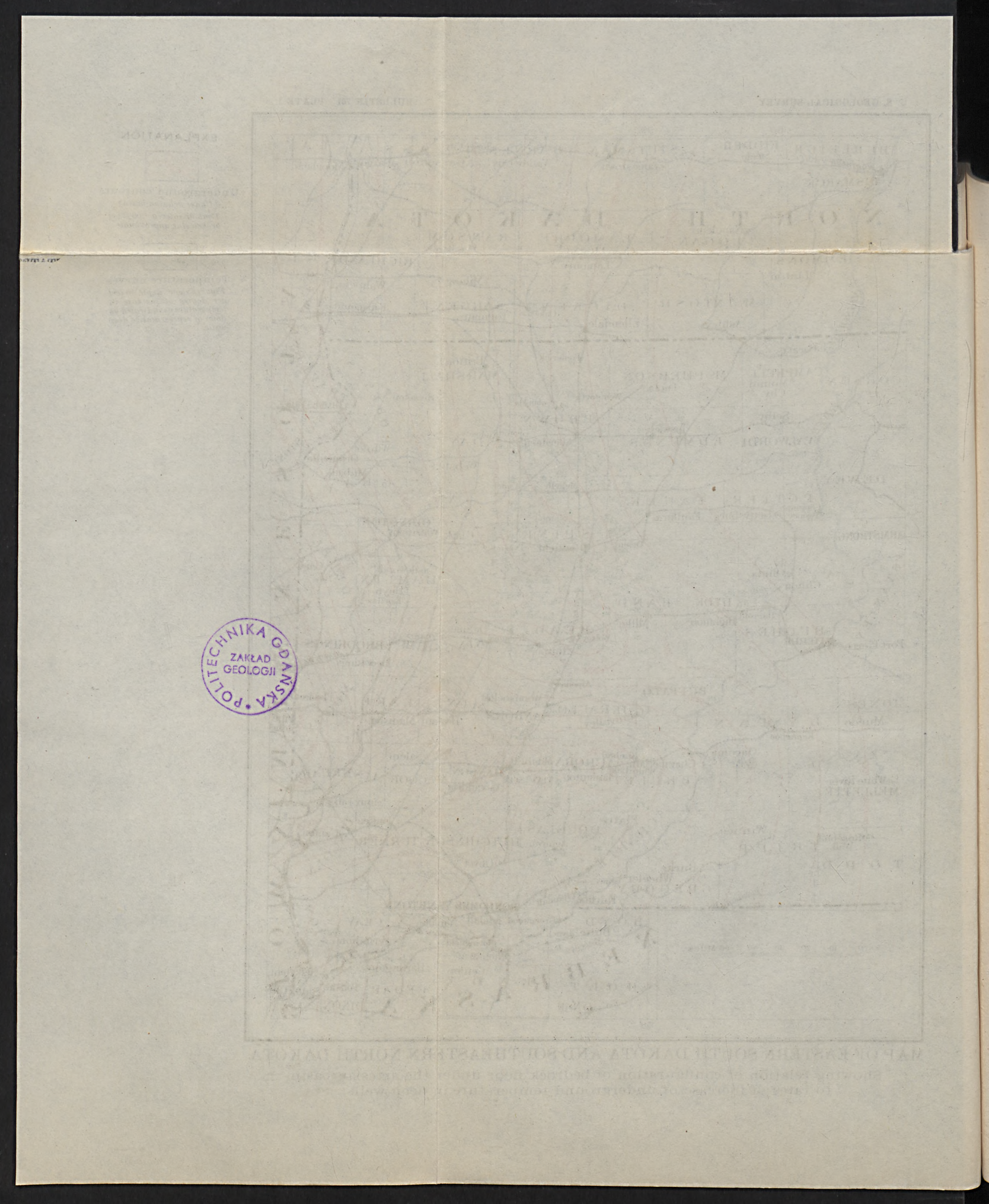
Of the 281 wells given in the above list all but 8 are in the region east of the Missouri. A large proportion of these are in Beadle, Brown, Faulk, Edmunds, Hand, and Spink counties, where many are close together. Records from representative wells in Aurora, Bon Homme, Buffalo, Charles Mix, Davison, Day, Douglas, Gregory, Hughes, Hutchinson, Hyde, Jerauld, Kingsbury, Marshall, Sanborn, and Yankton counties indicate the geothermal gradient in an area of wide extent. The deep artesian wells at Cheyenne Agency, with a rate of increase of 1° in about 35 feet; at the head of Oak Creek, northeast of Rosebud, with a rate of 1° in 23½ feet; and at Kennebec, with a rate of 1° in nearly 26 feet, extend the area. The flow from the Highmore well is too small to give a reliable indication of the temperature of the water at the source of the flow. In Plate I are shown the principal data for the eastern part of the State. The figures indicate feet to the degree of increase in representative wells. The lines connect wells of the same rates for 20, 25, 30, 35, 40, 45, and 50 feet to the degree and delimit the zones of intermediate rates. They are not isogeotherms, but if the well temperatures were calculated to some uniform depth, such as 500 to 1,000 feet, and these connected by isogeothermal lines, these lines would be parallel to the rate lines on the map.

In general, it will be seen from Plate I that the rate is nearly uniform in groups of wells, but it varies from place to place with most remarkable regularity. In the James River valley from Ashton to Aberdeen it is 1° in 40 to 45 feet. To the west and to the south through Redfield and in the east-central part of Beadle County it is 1° in less than 35 to 40 feet. At Wolsey and Alpena it is 1° in about 23 feet, and at Pierre, Crow Creek, and Chamberlain it is 1° in less than 30 feet. This zone of high rates extends down the Missouri Valley through Springfield and Yankton counties, S. Dak., and the northern part of Boyd, Knox, Cedar, and Dixon counties, Nebr. At Fort Randall the rate reaches a maximum of 1° in 17½ feet. The rate decreases rapidly to the north and east, as shown by scattered wells in Brule, Aurora, Davison, Douglas, Hutchinson, Sanborn, and Bon Homme counties. The rapid change from Springfield to Tyndall and the regular but less rapid diminution from Alpena to Mitchell are notable features in the "cooler" area.

The records in the western part of the State are diverse. The flow from a 515-foot well near Belle Fourche had a temperature of 54°, indicating a rate of 1° in 51½ feet, but a flow at 323 feet gave a less rate. The flow from the Orman well, 1,417 feet deep, with a temperature of 94°, indicated a rate of 1° in 28.3 feet, and the large flow from the 2,985-foot well at Edgemont indicated a rate of 1° in

MAP OF EASTERN SOUTH DAKOTA AND SOUTHEASTERN NORTH DAKOTA

Showing relation of configuration of bedrock floor under the artesian basin to rates of increase of underground temperature in deep wells.



39 feet, or nearly the same as the rate indicated by the record of a thermometer I sunk in an old 725-foot hole at Buffalo Gap, 30 miles. northeast of Edgemont

EOLOGIC RELATIONS.

Except the Edgemont wells, which draw from Cambrian sandstone, the many wells given on the list draw from the Dakota and associated sandstones. In the western part of the State these sandstones overlie "Red Beds" and a thick succession of Paleozoic limestones and sandstones, but east of the Missouri they lie directly on pre-Cambrian granite or quartzite. They are overlain by shale of Upper Cretaceous age, which is 1,000 feet or more thick to the north but less to the south and along Missouri River from Chamberlain to Yankton. The strata are not flexed and present a gentle down slope to the west over a wide area. The sections in figure 3 show the relations.

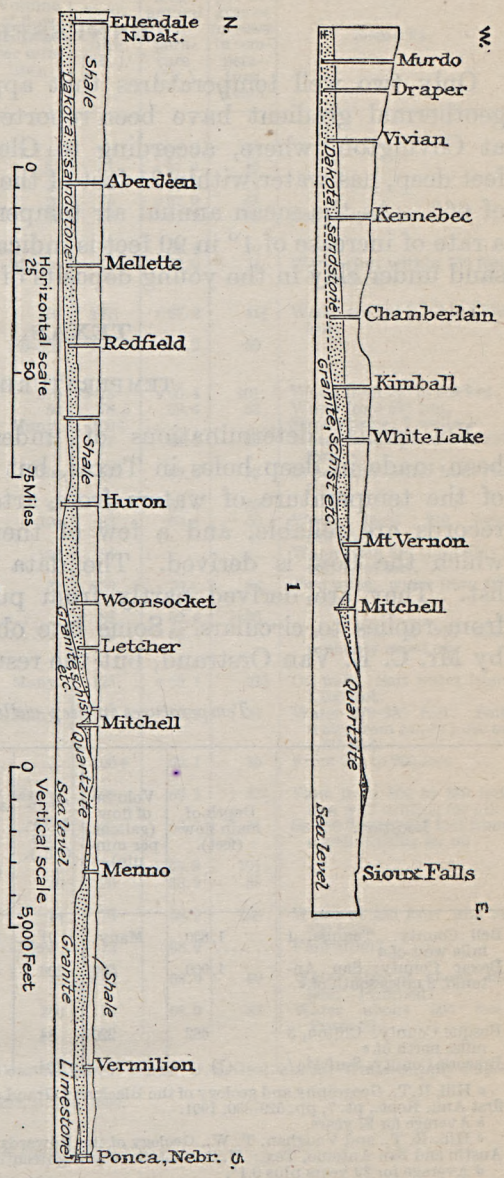


FIGURE 3.—Sections across eastern South Dakota. 1, Section from west to east; 2, section from north to south.

On Plate I are shown the principal features of configuration of the granite and quartzite bedrock floor on which the water-bearing beds lie. This floor has been reached by numerous holes, so that its position is well known at many localities. A more detailed

representation of it and the data used in constructing the map are set forth in my report on the geology of South Dakota.[1]

TENNESSEE.

Only two well temperatures that appear to throw light on the geothermal gradient have been reported from Tennessee. One is at Covington, where, according to Glenn,[2] the railroad well, 533 feet deep, has water within 31 feet of the surface, with a temperature of 66°. As the mean annual air temperature at this place is 60.1°, a rate of increase of 1° in 90 feet is indicated. The water is in coarse sand under clay in the young deposits of the Mississippi embayment.

TEXAS.

TEMPERATURES.

No special determinations of underground temperature have been made in deep holes in Texas, but there are numerous records of the temperature of waters from artesian wells. Some of these records are reliable, and a few of them indicate the depth from which the flow is derived. The data are given in the following list. They are derived partly from published reports and partly from replies to circulars. Some late observations have been made by Mr. C. E. Van Orstrand, but the results are not yet published.

Temperatures in deep wells in Texas.

Location.	Depth of main flow (feet).	Volume of flow (gallons per minute).	Temperature (°F.).	Mean annual temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Bell County: Temple, 1 mile west of.[a]	1,850	Many.	91	[b] 65.8	73½	"Water from bottom."
Bexar County: San Antonio, 2 miles south of.[c]	1,900	500	106	[d] 68.0	50	Sulphur water. Small flows at intervals below 1,535 feet, possibly not cased off.
Bosque County: Clifton, 3 miles north of.[e]	662	220	84	67.1	39	Water also at 182 and 610 feet, probably cased off.
Brazoria County: Surfside[f].	(?)	.....	[g] 104	.....	.....	

[a] Hill, R. T., Geography and geology of the Black and Grand prairies, Tex.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, pp. 529–530, 1901.
[b] Average for 27 years.
[c] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 22, pp. 294–297, 1897.
[d] Average for 32 years plus 0.1°.
[e] Hill, R. T., op. cit., p. 490.
[f] Fenneman, N. M., Oil fields of Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 282, pp. 49, 56, 1906.
[g] Idem, p. 87.

[1] Darton, N. H., U. S. Geol. Survey Water-Supply Paper 227, pl. 10, pp. 33–40, 1909.
[2] Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of adjacent area in Illinois: U. S. Geol. Survey Water-Supply Paper 164, p. 117, 1906.

Temperatures in deep wells in Texas—Continued.

Location.	Depth of main flow (feet).	Volume of flow (gallons per minute).	Temperature (°F.).	Mean annual temperature (°F.)	Depth per degree of increase in temperature (feet).	Remarks.
Burleson County:						
Myers	860	30	90	[a] 67.9	38	
Bryan, 12 miles from	835	35	85	[a] 67.9	49	
Do	635	22	76	[a] 67.9	78	
	550	20	76	[a] 67.9	63	
Whittaker, 3½ miles southeast of. [b]	850	50	77	[a] 67.9	88	Gas escapes also.
Denton County: Denton [c]	550	.....	72	64.4	70	
El Paso County: Fort Bliss.	403	Many.	76	[d] 62.9	31	Water rises within 130 feet of surface.
Falls County:						
Marlin [e]	3,330	150	147	[f] 67.2	41½	Water sand at 3,310 to 3,330 feet.
Many other wells in county.	1,750–1,850	150–300	103	67.2	50	
Galveston County:						
Alta Loma, 30 wells	875–950	310	75–78	[g] 69.4	101	Water from 740 to 868 feet.
Fairwood [h]	575	50	78.5	69.4	63	Water from 575 feet.
High Island [i]	142–203	Many.	100+	.....	.....	Strong brine; 7 wells.
Hitchcock [j]	726	70	77	69.4	89	Water sand from 678 to 726 feet.
Hitchcock, 1½ miles northwest of.	710	100	77	69.4	93	16 pounds; water from 710 feet.
Hitchcock, near	768	45	78	69.4	89	
Galveston, 28th and Church streets. [k]	810	125	83	69.4	60	Water from 810 feet; brackish.
Galveston, 36th and Church streets. [k]	1,365	243	84	.....	.....	Water from 810 (probably) and 1,365 feet.
Galveston, 10 miles southwest of. [k]	827	37	80	70±	83	Two wells; water from 827 feet.
Do	797	.....	83	69.4	58	
Grimes County: Navasota [l]	830	.....	80	[m] 68.1	70	Water also at 250 feet, probably cased off.
Hardin County:						
Batson [n]	1,200	Many.	125	[o] 69.1	21½	Oil well. Salt water from 1,200 feet.
Batson, Higgins No. 4	1,159	Many.	101	69.1	34	Water 970–985 feet. Salt water from sands 1,080 to 1,130 feet.
Saratoga, 3 miles west of. [p]	958	.....	100+	69.1	30	From 938 to 950 feet.
Sourlake	880+	Many.	100	69.1	27½	Flow from 850 to 880 feet in a well drilling for oil.
Sourlake	985	.....	101	69.1	31	Saline flow at 985 feet from a well drilling for oil.
Harris County:						
Cedar Bayou [q]	727	5	76	[r] 68.9	101	
Cedar Bayou, 3 miles northwest of.	410	30	76	68.9	86	
Cedar Bayou	548	14	73	68.9	128	Water at 525 feet; also at 320 feet.
Harrisburg, ½ mile east of.	640	Flow.	72	68.9	.....	Flow from?
Houston, Commerce and Fannin streets.	900	25	[s] 82	68.9	69	Water also at about 480 feet. Pumped.
Houston, Y. M. C. A	500	200	75	68.9	82	Water about 500 feet. Pumped.

[a] Average at College Station for 27 years.
[b] Taylor, T. U., Underground waters of Coastal Plain of Texas: U. S. Geol. Survey Water-Supply Paper 190, p. 60, 1907.
[c] Fifty-first Cong., 1st sess., S. Ex. Doc. 222, p. 264, 1890.
[d] El Paso average for 29 years.
[e] Hill, R. T., op. cit., p. 645.
[f] Mean annual temperature of Waco for 28 years plus 0.1°.
[g] Galveston average for 46 years.
[h] Texas Geol. Survey Fourth Rept., p. 101, 1892.
[i] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 139–141, 1914.
[j] See Singley, J. A., Report on artesian wells of Gulf coastal slope, p. 102, Austin, June, 1893.
[k] Deussen, Alexander, op. cit., pp. 157, 160, 164.
[l] Fifty-first Cong., 1st sess., S. Ex. Doc. 222, p. 341, 1890.
[m] College Station average plus 0.2°.
[n] Fenneman, N. M., Oil fields of Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 282, pp. 49, 56, 1906.
[o] Beaumont average for 16 years.
[p] Hayes, C. W., and Kennedy, William, Oil fields of Texas–Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, pp. 59–60, 1903. Also in Fenneman, N. M., op. cit., p. 47.
[q] Average for 16 years.
[r] Houston average for 27 years.
[s] U. S. Geol. Survey Water-Supply Paper 335, p. 230, 1914.

Temperatures in deep wells in Texas—Continued.

Location.	Depth of main flow (feet).	Volume of flow (gallons per minute).	Temperature (°F.).	Mean annual temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Hays County: San Marcos	1,490	100	73	67.5	271	Small flow at 1,345 feet, probably cased off.
Jefferson County:						
Beaumont, 1 mile west of.	1,034	8	[a] 4	[b] 69.1	204	Flow from 1,000 feet; higher flows may mingle.
Port Arthur	1,400±	Many.	[a] 80	69.1	128±	Flows mineral water. Source not known.
La Salle County: Cotulla [c]	1,008	Many.	86	[d] 71	67	Flow supposed to be from 1,008 feet.
Matagorda County: Big Hill.	722	Many.	99.6	[e] 70	23½	Flow from 700–730 feet.
McLennan County:						
Bruceville	1,565	150	95	[f] 67.1	56	Water at 500 feet probably cased off.
China Springs, 12 miles northwest of Waco.	1,380	Many.	102	67.1	37	Flows at 500, 600, 800, and 1,100 feet, probably cased off.
Hermosa, near Waco	1,730	150	103	67.1	48	Flows at 670 and 1,400 feet. (Hill.)
McGregor [g]	1,030	Many.	82	67.1	69	Water also at 502 feet. (Hill.)
McGregor	991	350	82	67.1	66½	
Waco:						
5 miles west of	1,470	350	90	67.1	64	Cased to 735 feet.
Moore's well [h]	1,852	Many.	103	67.1	51½	First water at 1,000 feet. (Hill.)
11 wells of Water Co. [i]	1,828–1,860	Many.	103	67.1	51	Flows at 700-800 and 1,100 feet also.
	1,607	Many.	97	67.1	53½	Do.
	1,812	Many.	100	67.1	55	Do.
	1,820	Many.	102½	67.1	51	Do.
	1,860	Many.	103	67.1	52	Flow from 1,800 to 1,815 feet. (Hill.)
	1,776	Many.	103	67.1	49½	
	1,866	Many.	103½	67.1	51	Sandstone, 1,760–1,861 feet. (Hill.) [j]
Nacogdoches County: Nacogdoches.	500	500	[k] 74	[l] 65.4	39½	Flow from 340–500 feet.
Navarro County:						
Corsicana No. 1	2,483	200	126	[m] 66	41	Flow at bottom.
Corsicana No. 2	2,515	200	126	66	40	Water sand, 2,400 to 2,460 feet. [n]
Corsicana No. 3	2,500	200	126	66	41½	
Tarrant County:						
Fort Worth	3,250	Many.	[o] 126	[p] 65	18½	Cased to main flow at 1,127 feet.
Marine, ½ mile northeast	1,200	545	78	65	74	Water from 960–1,000 feet. [q]
Travis County:						
Austin Natatorium [r]	1,875	300	100	[s] 67.4	[t] 51	Cased to 1,100 feet. Small flow at 1,215 feet; not cased off. Main flow 1,875 feet from sandstone (1,675 to 1,875 feet).
Manor [u]	2,560	700	93	67.4	[v] 48½	Water-bearing rock 1,250 to 1,400 feet.
Waller County: Hempstead	1,131	100	80	[w] 68.6	97½	Flow from 1,110 feet.
Williamson County: Roundrock.	1,400	Many.	95	[x] 67.4	51	Pumped.
Zavalla County: Carrizo Springs, 22 miles north.	910	Several.	[y] 90	[z] 72	40	Cased 720 feet to main flow.

[a] U. S. Geol. Survey Water-Supply Paper 335, p. 265, 1914.
[b] Average for 16 years.
[c] Rept. Special Comm. on Irrigation and Reclamation of Arid Lands, U. S. Senate, vol. 4, p. 62, 1890.
[d] Eagle Pass average for 40 years.
[e] Galveston average plus 0.6°.
[f] Waco average for 28 years.
[g] Rossler, A. R., Report on preliminary investigation to determine proper location of artesian wells within the area of the 97th meridian and east of the foothills of the Rocky Mountains: 51st Cong., S. Ex. Doc. 222, p. 257, 1890.
[h] 51st Cong., 1st sess., S. Ex. Doc. 222, p. 340, 1890.
[i] Hill, R. T., op. cit., p. 108.
[j] Idem, p. 542.
[k] Average for 28 years.
[l] Average for 18 years.
[m] Hill, R. T., op. cit., p. 311.
[n] Hill, R. T., op. cit., p. 641.
[o] Idem, p. 576.
[p] Average for 22 years.
[q] Hill, R. T., op. cit., p. 577.
[r] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 284.
[s] Average for 61 years.
[t] Calculated to 1,675 feet.
[u] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 284–286, 1898; Twenty-first Ann. Rept., pt. 7, pp. 511–514, 1901; Water-Supply Paper 335, p. 355, 1914.
[v] Calculated to 1,250 feet.
[w] Houston average minus 0.3°.
[x] Austin average.
[y] Eagle Pass average plus 0.1°.
[z] U. S. Geol. Survey Bull. 298, p. 286, 1906.

SUMMARY.

It is difficult to judge the relative values of the Texas temperature records. Some may not be correct, and others may not represent the temperature at the depth stated owing to the mingling of flows. The flow from the deep well at Marlin is supposed to come from a depth of 3,350 feet, and if so it indicates a rate of 1° in 42 feet. The several wells at Waco, not far southeast of Marlin, give rates of 1° in 49½ to 53 feet. Other wells in the same county (McLennan) indicate 1° in 48, 64, 66½, 69, and 56 feet, but the apparent lower rate is possibly due to the ingress of higher waters. The warm flow from a depth of 1,380 feet at China Springs, 12 miles northwest of Waco, indicates the exceptionally high rate of 1° in nearly 37 feet. A similar rate is indicated by the Clifton well in Bosque County, about 25 miles northwest of China Springs. The three deep wells at Corsicana, still farther north, give a rate of 1° in 40 to 41½ feet. Fort Worth has a rate of 1° in 18½ feet if all the flow is derived from a depth of 1,127 feet, as stated. The rate at Nacogdoches may be as high as 1° in 39½ feet if the flow comes from a depth of 340 feet. The Austin wells indicate rates of 1° in 48½ and 51 feet, but the true rate here may be considerably less if the flow is from a deeper source than the depth used in the calculations. The Round Rock figure is uncertain, but the rates for Hempstead and Navasota appear to be valid. The data for Harris County, Port Arthur, and Beaumont are not satisfactory, and the wells 2 miles south of San Antonio and at Cotulla and Temple may not give reliable data. The temperature given for the San Marcos well is doubtless unreliable. The five wells in Hardin County appear to have rates of 1° in 21½, 27½, 30, 31, and 34 feet, without likelihood of much error. The Big Hill 722-foot well has a similar rate, and the High Island well evidently indicates a steep rate. The rate indicated by the Galveston County wells varies, but the figures 60 and 63 feet to the degree appear the most accurate, there being uncertainty as to the source of the water in the others. As the water at Fort Bliss is pumped the temperature given may not be as high as that in the bottom of the well, but the figure given (76°) indicates that the rate is 1° in at least 31 feet.

GEOLOGIC RELATIONS.

The wells in the above list penetrate a great variety of formations, which are mostly, however, of Cretaceous and Tertiary age. In most parts of the area the shales are tilted at low angles and in places traversed by faults. No igneous rocks are reported near any of the wells listed, and the granites or other old bedrocks are far beneath the surface. The wells in the southeastern part of the State and along the coast draw from sands of Tertiary age. In the oil fields of Hardin County there are sharp local uplifts or domes. The Nacogdoches well draws from lower beds in the Eocene.

The group of wells extending from north to south across the center of the State draw their waters from sands in the Trinity group, which is low in the Cretaceous. The deep boring at Fort Worth passed through the base of these sands and penetrated the Paleozoic rocks for more than 2,000 feet. At Marlin, in Falls County, where the lowest sand lies deep, it was necessary to sink 3,330 feet to reach it. The Corsicana wells draw from the Woodbine sand, in the Upper Cretaceous, considerably above the highest beds of the Trinity. The 1,900-foot well 2 miles south of San Antonio is believed to have not quite reached the base of the Edwards limestone.[1] The San Marcos and San Antonio wells are situated near a great fault. The Fort Bliss well draws from the Quaternary valley fill.

UTAH.

A few well temperatures in the Milford-Beaver region, in southwestern Utah, have been reported by Lee.[2]

Temperatures in wells in Utah.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Depth per degree of increase in temperature (feet).[a]	Remarks.
Milford	425	25	72	18	
Do	750	37	80	24	
Do	381	13	65	23	
Do	280	7	68	14	
Milford, railroad well	310	30	71	14	
Sec. 28, T. 29 S., R. 7 W	213	.....	54	36?	Pumped.
Sec. 36, T. 29 S., R. 8 W	314	7	74	12	Flows at 200 and 314 feet.
Sec. 28, T. 29 S., R. 8 W	385	.....	53	77?	
Sec. 5, T. 28 S., R. 10 W	286	8	71	12	
Greenville School	244	11	68	12	Flows also at 180 feet.
Neels	1,998	.....	Hot.	.....	Hot water 1,205 feet and below. Reached granite.

[a] Calculated from Milford mean for 1916, 48.2°. Water in wells 60 to 66 feet deep is stated to have a temperature of 51° to 55°.

The waters are decidedly thermal considering the slight depths of the wells. The cause of the heat is not apparent. Probably the two wells in the list showing temperatures of 53° and 54° are cooled by pumping or by the ingress of shallow water.

All these wells are in the Quaternary clay, sand, and gravel deposits of the Lake Bonneville basin. The boring at Neels reached granite.

[1] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 295, 1898.

[2] Lee, W. T., Water resources of Beaver Valley, Utah: U. S. Geol. Survey Water-Supply Paper 217, pp. 24–33, 1908.

VIRGINIA.

RICHMOND COAL FIELD.

In 1836 to 1842 Rogers [1] determined temperatures in the coal mines in the Newark group west of Richmond, Va., the results of which he discussed at considerable length. The coal measures consist mostly of sandstone lying in a basin underlain by granitic rocks; the coal is in the basal beds. The strata have steep dips and are greatly broken, and owing to this condition a large amount of water penetrates into the mines. The following results were obtained:

Temperatures in coal mines near Midlothian, Va.

Location.	Depth (feet).	Temperature (°F.).	Depth per degree of increase in temperature (feet).[a]	Remarks.
Greenhole pit	100	58.0	.....	In pool of water in bottom.
Mills & Reed's pit	318	59.5	.....	In large flow of water from galleries.
Do	375	61.0	125	Do.
Do	420	63.0	84	Do.
Black Heth engine pit	412	63.0	83	Pool of water in gallery not working, also in floor.
Wills & Michael's pit	386	62.0	96	Pool in bottom main shaft.
Black Heth pit	570	65.5	76	Pool in lowest level.
Black Heth new shaft	380	61.5	.....	Crevice in rock in bottom cooled by drippings from above.
Midlothian 1842 shaft	330	61.75	88	Spring in wall.
Do	600	66.25	74	Small streams at bottom some distance above coal.
Midlothian 1839 shaft	780	68.75	72	Water mixed with some drippings from higher up.

[a] Calculated from mean annual air temperature at Richmond, 58.5° (37-year average to 1916) minus 0.5° for difference in the altitude and latitude. Rogers used 56.75°.

The first observation was made in a mine in operation and the last four in shafts just completed or in progress. Exclusive of the three first and one in the new Black Heth shaft, the average rate indicated by the others is 1° in 82 feet.

The figures indicate a less rate in the old workings than in the new shafts, a difference which may be due to the cooling by seepage and ventilation. Rogers made the following comments on the results:

> Comparing the three last observations, the two former of which were made in the same shaft and the last in one only a few hundred feet removed, there is ground for inferring that the rate at which the temperature increases grows less as the depth augments. In descending from 330 feet to 600—that is, through 270 feet—the rise of temperature is 4.5°; while in descending from 600 to 780, or through 280 feet, the rise is only 2.5°. This difference would, I think, have been less could I have obtained the temperature at 780 feet free from the cooling influence of the copious drippings from above. Yet even with the most liberal allowance, there would still remain evidence of a diminishing rate of increase with the depth.

[1] Rogers, W. B., Observations of subterranean temperature in the coal mines of eastern Virginia: Assoc. Am. Geologists and Naturalists Trans., 1840–1842, pp. 532–538, 1843; Reprint of annual reports and other papers on the geology of the Virginias, pp. 567–574, New York, 1884.

Rogers considered the observations at 330 and 600 feet in the Midlothian shaft the most reliable, and these give a rate of 1° in 88 and 74 feet, respectively; the difference between them is 1° in 60 feet. The rate for the 780-foot reading (1° in 72 feet) is accordant, although, as suggested by Rogers, the water may be cooled slightly by drippings from above.

FORT MONROE.

In 1902 a 2,130-foot boring was made at Fort Monroe, and Capt. C. P. Townsley kindly lowered a Darton thermometer in it. After two hours the instrument recorded 92.5°. As the mean annual air temperature at Newport News is about 59.4°, a rate of 1° in 64 feet is indicated. The boring passed through Tertiary and Cretaceous formations of the Coastal Plain to the basement of pre-Cambrian granite. The hole was full of salty water.

REEDVILLE.

At Reedville, in Northumberland County, the 85-gallon flow from a 680-foot well is reported to have a temperature of 78°. As calculated from the mean annual air temperature at Warsaw, 56.4°, a rate of 1° in 31½ feet is indicated.

WASHINGTON.

YAKIMA ARTESIAN BASIN.

There are numerous flowing wells in the vicinity of Yakima which afford data as to underground temperature. In most of them, however, several flows are intermixed, so that the observations do not indicate the temperature at any definite depth. There are three wells which reach the upper flow only and three others in which the casing is so set that only one flow can enter. They are in an area about 1½ miles long and within 120 feet elevation. The data for these six wells, as given by Geo. Otis Smith,[1] are as follows:

Temperature at different depths in six wells in Yakima artesian basin, Wash

Depth of flow (feet).	Flow (gallons per minute).	Temperature (° F.).	Depth per degree of increase in temperature (feet).[a]
515	Many.	70.7	25.0
637	120	72.2	28.9
835	60	73.2	36.1
625	Many.	73.2	27.0
752	300	72.2	34.0
820	360	72.7	36.2

[a] Calculated on basis of mean annual air temperature of 50.1°, mean of 17 years given by United States Weather Bureau.

[1] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: U. S. Geol. Survey Water-Supply Paper 55, pp. 49-62, 1901.

It was noted by Smith that the rate of increase is highest in the shallower wells.

Waring [1] has reported that a large flow from a well on the Yakima Indian Reservation, in sec. 34, T. 11 N., R. 18 E., has a temperature of 68°. The main flow is from a depth of 507–512 feet, possibly with a small admixture of water from 492 feet. The rate indicated by this observation is 1° in about 28 feet.

Russell [2] has given temperatures of flows from several wells in the Yakima Valley, but the flows are small and the source of the water is not definitely located. One of these wells, in sec. 31, T. 13 N., R. 20 E., has a 2-gallon flow with a temperature of 73° from a depth of 886 feet; another, in sec. 3, T. 12 N., R. 20 E., only 314 feet deep, has a flow with a temperature of 75°.

WALLA WALLA.

In 1909 I noted the temperature of the large flows from several wells on the Blalock ranch west of Walla Walla. The flow from one well, 611 feet deep, had a temperature of 66.5°; that from another of similar depth, 67.25°; and that from a 563-foot well, 67°. It is stated that the casings extend to a depth of 540 feet to a 20-foot sheet of basalt under which is the water-bearing sand. As the mean annual air temperature of Walla Walla is 53.4° (23-year average) a rate of 1° in 41.4 feet is indicated, if the flow comes from a depth of 563 feet.

WHITMAN COUNTY.

It is reported that the flow from a 110-foot well at Pullman has a temperature of 60°, and that from a 176-foot well at Tekoa a temperature of 76°, but these figures may not be reliable. As the mean annual air temperature at Colfax is 47.8° and at Rosalia 46.5°, they indicate a very high rate. Doubtless heat from old lava flows is the cause.

WEST VIRGINIA.

There are many deep borings in West Virginia, and temperatures in a number of them have been determined by the late William Hallock,[3] by Johnson and Adams,[4] and by Van Orstrand.[5]

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[1] U. S. Geol. Survey Water-Supply Paper 316, p. 31–32, 1913.

[2] U. S. Geol. Survey Bull. 108, pp. 56–59, 1893.

[3] Hallock, William, U. S. Geol. Survey Thirteenth Ann. Rept., pt. 1, pp. 95–96, 1892; U. S. Geol. Survey Fourteenth Ann. Rept., pt. 1, pp. 159–160, 1893; Preliminary report of observations at the deep well, Wheeling, W. Va.: Am. Jour. Sci., 3d ser., vol. 43, pp. 234–236, 1892; Notes on further observations of temperatures in the deep well at Wheeling, W. Va.: Am. Assoc. Adv. Sci. Proc., vol. 40, p. 258, 1891; Subterranean temperatures at Wheeling, W. Va., and Pittsburgh, Pa.: School of Mines Quart., vol. 18, pp. 148–153, 1897; British Assoc. Adv. Sci., Rept., 62d meeting, pp. 129–131, 1910.

[4] Johnson, John, and Adams, L. H., On the measurement of temperatures in bore holes: Econ. Geology, vol. 11, pp. 741–762, 1916.

[5] U. S. Geol. Survey Press Bulletin 420, 1919. White, I. C., Discussion of the records of some very deep wells in the Appalachian oil fields of Pennsylvania and West Virginia, with temperature measurements by C. E. Van Orstrand [Morgantown, W. Va., 1918].

WHEELING.

The well tested by Hallock was on Boggs Run, 4 miles southeast of Wheeling. It was 4,771 feet deep, and although water was found at moderate depths it was cased off by 1,570 feet of 4¾-inch casing, so that the hole was dry when finished. The strata penetrated are nearly horizontal and begin high in the Carboniferous coal measures. Ordinary United States Signal Service self-registering thermometers were used. The following figures were obtained. Observations made two years later in water gave very closely accordant results. (See below.)

Temperatures at different depths in deep boring near Wheeling, W. Va.

	°F.		°F.		°F.
1,350 feet	68.75	2,625 feet	82.20	3,625 feet	96.10
1,592 feet	70.25	2,740 feet	83.65	3,730 feet	97.55
1,745 feet	71.70	2,875 feet	85.45	3,875 feet	100.05
1,835 feet	72.80	2,990 feet	86.60	3,980 feet	101.75
2,125 feet	76.25	3,125 feet	88.40	4,125 feet	104.10
2,236 feet	77.40	3,232 feet	89.75	4,200 feet	105.55
2,375 feet	79.20	3,375 feet	92.10	4,375 feet	108.40
2,486 feet	80.50	3,482 feet	93.60	4,462 feet	110.15

According to the Weather Bureau observations for 39 years the mean annual air temperature at Wheeling is 56.3°, but Hallock used 51.3°, the temperature found at a depth of 110 feet in a near-by coal mine. I believe 51.3° is too low, for temperatures taken in mine galleries are misleading. Two years later water at a depth of 103 feet in the deep well was found to have a temperature of 52.5°. The rate calculated to a depth of 4,462 feet from a mean annual air temperature of 56° is close to 1° in 83 feet; the rate from 1,350 to 4,462 feet is 1° in 75.2 feet; from 2,990 to 4,462 feet, 1° in 62.5 feet.

After taking temperatures in the deep hole near Wheeling when it was dry, Hallock[1] had opportunity to make an additional series two years later, when water stood within 40 feet of the top.

Comparison of temperatures in air and in water in deep well near Wheeling, W. Va.

Depth (feet).	Temperature in water, 1893 (°F.).	Temperature in air, 1891, interpolated (°F.).	Water temperature minus air temperature (°F.).
1,586	70.12	70.12	−0.03
1,921	73.95	73.82	+ .13
2,055	75.28	75.42	− .14
2,276	78.13	77.93	+ .20
2,396	79.54	79.45	+ .09
2,539	81.21	81.15	+ .06
2,669	[a]83.39	82.75	+ .64
2,793	84.56	84.41	+ .15
2,937	86.12	86.07	+ .05
3,057	87.42	87.50	− .08
3,196	89.27	89.30	− .03

[a] Doubtful.

[1] Hallock, William, Subterranean temperatures at Wheeling, W. Va., and Pittsburgh, Pa.: School of Mines Quart., vol. 18, pp. 148–153, 1897.

These determinations show that there is no important difference between the air and water temperatures in a hole.

Hallock made a few observations at a deep boring at Radsford, W. Va., but as the hole was wet he did not complete the determinations.

CHELYAN.

Johnson and Adams made many tests in the lower part of the 5,236-foot hole at Chelyan, near Charleston. The results appear to indicate a temperature of about 129° in the bottom. With a mean annual of 57.6°, average of 14 years at Charleston, this indicates a rate of 1° in 73.3 feet.

MANNINGTON.

The temperature determinations in the Hibbs No. 4 hole near Mannington were made with an electric resistance thermometer by Johnson and Adams and later with a mercury thermometer by Van Orstrand. The results were as follows, with rates of increase calculated from the 250-foot reading subtracted from those at lower depths, all as indicated by the electric measurement.

Temperatures in Hibbs No. 4 hole near Mannington, W. Va.

Depth (feet).	Electric thermometer (°F.).	Mercury thermometer (°F.).	Depth per degree of increase in temperature (feet).
100	56.0	53.6	----------
250	54.9	54.1	----------
500	57.5	56.7	96
750	60.7	60.1	86
1,000	63.9	63.5	83
1,250	66.5	66.2	86
1,500	68.6	68.5	91
1,750	70.7	70.7	95
2,000	73.1	73.2	96
2,250	75.6	75.4	97
2,500	78.9	78.8	94

If calculated from the mean annual air temperature the temperature of 78.9° in the bottom of the well indicates a gradient of 1° in 93 feet.

Observations by Mr. Van Orstrand in a group of wells of the South Penn Oil Co. gave the following results:

Temperature measurements in borings of South Penn Oil Co., near Mannington, W. Va.

Depths (feet).	Well 14, mean of 3 tests (° F.).	Well 6, mean of 3 tests (° F.).	Well 2 (° F.).	Well 4 (° F.).	Well 7 (° F.).	Well 9 (° F.).
100		55.4	53.8	53.6	54.18	52.23
250	60.1	56.7	55.2	54.1		
500	62.4	60.1	58.8	56.7	57.72	57.31
750		63.5	62.4	60.1		
1,000	67.5	66.6	65.8	63.5	64.62	63.82
1,250		69.3	68.0	66.2		
1,500	72.0	71.6	70.0	68.5	70.23	70.30
1,750		73.4	72.9	70.7		
1,980		71.6				
2,000	75.4		75.2	73.2	75.00	75.22
2,250			78.3	[a]75.4		
2,500	[b]77.9		80.6	78.8	80.13	77.95
2,650			82.6		81.18	
2,750	81.1			81.9		
2,888					[c]83.19	
3,000	[d]86.4			[b]81.3		
3,134				85.3		
3,225				88.3		

[a] Some gas.
[b] Gas at 2,560 feet.
[c] Some gas at 2,875–2,888 feet.
[d] Gas at 2,940 feet.

The rates of increase indicated by these observations are as follows: Well 14, 250 to 3,000 feet, 1° in 104 feet; well 6, 100 to 1,980 feet, 1° in 116 feet; well 2, 100 to 2,650 feet, 1° in 90 feet; well 4, 100 to 3,225 feet, 1° in 90 feet; well 7, 100 to 2,888 feet, 1° in 96 feet; well 9, 100 to 2,500 feet, 1° in 93 feet.

SPENCER.

The 3,403-foot hole bored by the Hope Gas Co. 22 miles east of Spencer, Clark County, was tested at 100-foot intervals to 3,250 feet by Mr. Van Orstrand with the following results:

Temperature measurements in well 22 miles east of Spencer, W. Va.

	°F.		°F.		°F.
100 feet	54.1	1,000 feet	65.1	1,900 feet	74.9
200 feet	55.0	1,100 feet	66.0	2,000 feet	76.2
300 feet	56.3	1,200 feet	67.0	2,100 feet	77.5
400 feet	57.8	1,300 feet	68.5	2,200 feet	79.0
500 feet	59.4	1,400 feet	69.9	2,200 feet	80.3
600 feet	60.7	1,500 feet	70.9	2,400 feet	81.4
700 feet	61.7	1,600 feet	72.6	2,500 feet	82.6
800 feet	62.7	1,700 feet	73.5	2,600 feet	83.4
900 feet	3.66	1,800 feet	5.47	3,250 feet	91.9

The rates of increase indicated by these observations are as follows: 100 to 3,250 feet, 1° in 83.3 feet; 1,000 to 3,250 feet, 1° in 84 feet.

VOLCANO JUNCTION.

The 4,527-foot well at Sandhill, 4 miles north of Volcano Junction, Wood County, W. Va., was tested at different depths by Mr. Van Orstrand with a mercury thermometer for some tests and electrical resistance coil for others. The results were as follows:

Temperature measurements in well 4 miles north of Volcano Junction, W. Va.

	°F.		°F.		°F.
100 feet	[1]54.2	1,500 feet	68.0	3,250 feet	[1]95.0
500 feet	57.2	1,750 feet	[1]70.9	3,500 feet	[1]99.0
700 feet	58.6	2,000 feet	74.8	3,750 feet	[1]103.7
800 feet	59.6	2,250 feet	[1]79.1	4,000 feet	[1]108.8
900 feet	61.1	2,500 feet	82.7	4,100 feet	[1]110.7
1,000 feet	62.8	2,750 feet	[1]86.2	4,250 feet	[1]113.1
1,250 feet	65.2	3,000 feet	91.1		

The rates of increase indicated by these observations are as follows: 100 to 4,250 feet, 1° in 70½ feet; 1,000 to 4,250 feet, 1° in 64.6 feet.

GRANTVILLE.

A 4,610-foot hole on the Poling farm, 5 miles southeast of Grantsville, W. Va., was tested by Mr. Van Orstrand with the following results:

Temperature measurements in well 5 miles southeast of Grantsville, W. Va.

	°F.		°F.		°F.
100 feet	55.3	1,200 feet	67.2	2,400 feet	80.5
200 feet	55.8	1,300 feet	68.3	2,500 feet	81.8
300 feet	56.8	1,400 feet	69.5	2,600 feet	82.9
400 feet	57.9	1,500 feet	70.3	2,700 feet	84.2
500 feet	59.2	1,600 feet	71.7	2,800 feet	85.4
600 feet	60.4	1,700 feet	72.5	2,900 feet	86.8
700 feet	61.6	1,800 feet	73.2	3,000 feet	88.1
800 feet	62.9	2,000 feet	75.4	3,500 feet	95.2
900 feet	64.1	2,100 feet	76.9	4,000 feet	101.8
1,000 feet	65.2	2,200 feet	78.1	4,500 feet	110.8
1,100 feet	65.9	2,300 feet	79.4		

Some of the rates of increase indicated by these figures are as follows: 100–4,500 feet, 1° in 80 feet; 100–2,800 feet, 1° in 90 feet; 1,000–4,500 feet, 1° in 76.7 feet; 2,000–4,500 feet, 1° in 70.3 feet; 3,000–4,500 feet, 1° in 66 feet.

[1] Taken with mercury thermometer.

SHINNSTON.

The 4,920-foot hole bored by the Hope Gas Co. on the farm of E. Robinson at Wyatt, 5 miles northwest of Shinnston, was tested at every hundred feet to a depth of 2,000 feet by Mr. Van Orstrand with the following results:

Temperature measurements in a 4,290-foot hole at Wyatt, W. Va.

	°F.		°F.		°F.
100 feet	54.5	800 feet	62.0	1,500 feet	68.4
200 feet	55.5	900 feet	62.9	1,600 feet	[1] 68.0
300 feet	56.3	1,000 feet	64.2	1,700 feet	70.7
400 feet	57.5	1,100 feet	65.0	1,800 feet	71.9
500 feet	58.9	1,200 feet	65.6	1,900 feet	72.9
600 feet	59.9	1,300 feet	66.5	2,000 feet	74.1
700 feet	61.0	1,400 feet	67.7		

The rate of increase indicated by the difference in temperature between 100 and 2,000 feet is close to 1° in 96 feet; from 1,000 to 2,000 feet the rate is 1° in 101 feet.

LAKE WELL.

This well reached a depth of 7,579 feet when drilling ceased in 1919. It is about 8 miles south of Fairmont, W. Va. Van Orstrand found the temperature at 7,500 feet to be 168.6°, indicating an average rate of temperature increase of 1° in 66 feet.

Mr. Van Orstrand has also given a series of measurements from 100 to 5,400 feet as follows:

Temperature measurements in well on Lake Farm, 4 miles northeast of Valley Falls, W. Va.

	°F.		°F.		°F.
100 feet	53.7	1,300 feet	69.2	3,250 feet	93.6
200 feet	55.8	1,400 feet	70.6	3,500 feet	95.4
300 feet	57.5	1,500 feet	71.8	3,750 feet	100.9
400 feet	58.8	1,600 feet	73.1	4,000 feet	104.5
500 feet	59.9	1,700 feet	74.3	4,250 feet	106.0
600 feet	61.0	1,800 feet	75.3	4,500 feet	111.4
700 feet	62.2	1,900 feet	76.7	4,750 feet	116.2
800 feet	62.8	2,000 feet	78.4	5,000 feet	120.7
900 feet	64.4	2,250 feet	82.4	5,250 feet	126.1
1,000 feet	65.6	2,500 feet	86.0	5,400 feet	129.2
1,100 feet	66.8	2,750 feet	89.2		
1,200 feet	68.1	3,000 feet	90.5		

The rate of increase from 100 to 5,400 feet is 1° in 70 feet.

GOFF WELL.

The well on the Goff farm is about 8 miles northeast of Clarksburg in the northern part of West Virginia. Its depth is 7,386 feet.

[1] A small discharge of gas occurs ot 1,610 feet.

Tests were made by Mr. Van Orstrand at various depths in the well with the following results:

Temperature measurements in Goff well 4 miles northeast of Bridgeport, W. Va.

	°F		°F.		°F.
100 feet	55.6	1,300 feet	66.5	2,500 feet	81.0
200 feet	56.3	1,400 feet	67.2	3,000 feet	87.6
300 feet	57.5	1,500 feet	67.8	3,500 feet	93.8
400 feet	58.8	1,600 feet	68.0	4,000 feet	100.0
500 feet	60.2	1,700 feet	67.8	4,500 feet	107.2
600 feet	61.6	1,800 feet	70.8	5,000 feet	114.2
700 feet	62.5	1,900 feet	73.6	5,500 feet	122.3
800 feet	63.5	2,000 feet	74.9	6,000 feet	132.1
900 feet	64.5	2,100 feet	76.1	6,500 feet	143.2
1,000 feet	65.3	2,200 feet	77.3	7,000 feet	153.2
1,100 feet	65.8	2,300 feet	78.3	7,250 feet	157.7
1,200 feet	65.5	2,400 feet	79.3	7,310 feet	[1] 158.3

Some of the rates of increase indicated by these figures are as follows: 100 to 7,310 feet, 1° in 70.2 feet; 100 to 7,000 feet, 1° in 70.7 feet; 100 to 5,000 feet, 1° in 83.6 feet; 1,000 to 7,310 feet, 1° in 67.8 feet; 2,000 to 7,310 feet, 1° in 63.7 feet; 4,000 to 7,250 feet, 1° in 56.3 feet.

WISCONSIN.

TEMPERATURES.

Temperatures of flows of certain Wisconsin wells are given in the reports of the State Survey [2] and water-supply papers of the United States Geological Survey, but for the most part the depth from which the flows are derived is not given, and some of the wells are pumped. The following selected list may afford a few data of value:

[1] Regarded as about 0.5° F. too low.

[2] Weidman, Samuel, and Schultz, A. R., The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 35, 664 pp., 5 pls., 1915.

Temperatures in wells in Wisconsin.

Location.	Depth (feet).	Flow (gallons per minute).	Temperature (°F.).	Mean annual temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Crawford County:						
Prairie du Chien [a]	350–375	200	54	47.5	54	
Do	960–1,004	540	57	47.5	.....	
Green Lake County: Berlin.	425	Many.	52	[b] 45.2	63	Flow from below 324 feet.[c]
Marinette County: Marinette.	716	.....	49	[d] 43.3	71	Cased to 333 feet; water at 405–410 feet; not any below 415 feet.
Oconto County: Oconto	400	450	50	[e] 44.1	68	Cased to 225 feet; source of flow unknown.
Pepin County: Durand [f]	200	Many.	51	[g] 44.2	30	
Richland County: Richland Center.	748	2,400	53	[h] 45.3	96	Pumped 11 feet; water probably from considerably above bottom.
Sheboygan County: Sheboygan. [f]	1,475	225	[i] 59.1	[j] 45.7	100	Pumped 104 feet; main supply probably from 1,340 feet.
Vernon County:						
Genoa	450	200	52	[k] 46.7	87	Pumped 30 feet.
De Soto	446	126	52	[l] 46.7	84	Flow.
Walworth County: Elkhorn.	1,050	Many.	58	46	88	Air lift, pumped 155 feet.

[a] Calculated to depth of 1,340 feet.
[b] Oshkosh average for 28 years.
[c] Wisconsin Geol. and Nat. Hist. Survey Bull. 35, p. 364, 1914.
[d] Average at Menominee, Mich., for 18 years.
[e] Average for 26 years.
[f] Wisconsin Geol. and Nat. Hist. Survey Bull. 35, p. 502, 1914.
[g] Idem, p. 284.
[h] Viroqua average for 27 years plus 0.5°.
[i] Wisconsin Geol. and Nat. Hist. Survey, p. 569, 1914.
[j] Average for 18 years.
[k] Mean of La Crosse and Prairie du Chien.
[l] Delavan average for 24 years.

SUMMARY.

Exclusive of Sheboygan, Elkhorn, and Richland wells, of which the true underground temperatures are uncertain, there is a fair degree of accordance in the rates indicated by the Prairie du Chien, Berlin, Marinette, Genoa, De Soto, and Oconto wells. Owing, however, to some uncertainty as to the precise source of water, the figures can be regarded only as approximations. The temperature of the flow from relatively shallow wells at Durand indicates a high rate.

GEOLOGIC RELATIONS.

The wells in the above list are all in the Paleozoic rocks on the slope of the low structural dome whose summit is in the broad area of crystalline rocks that occupies the northern part of the State. There are no local disturbances of any note. All the wells draw from sandstone, either the St. Peter sandstone, as at Oconto and Sheboygan, or the Upper Cambrian, some distance below the St. Peter horizon. At Marinette the granite "bedrock" is reached at a depth of 712 feet, and at Richland at 665 feet. At Durand it is

not far below the bottom of the 200-foot well. At Sheboygan a hole 1,782 feet deep did not reach the bedrock. There is no apparent relation between the gradients and geologic conditions.

WYOMING.

The deep-well temperatures in Wyoming given in the following table were carefully determined with Darton thermometers sunk to the bottom of the holes by my assistants or myself.

Temperatures in wells in Wyoming.

	Depth (feet).	Temperature (°F.).	Mean annual air temperature (°F.).	Depth per degree of increase in temperature (feet).	Remarks.
Big Horn County:					
SW. ¼ SE. ¼ sec. 27, T. 102, R. 48, 10 miles southwest of Meteetse.	1,400	66	[a] 40	54	Dry hole; thermometer sunk by C. A. Fisher.
Cambria	1,475	59	[b] 45.2	107	Thermometer sunk by G. B. Richardson, 1899.
Newcastle, 2 miles west	374	63	45.2	21	Thermometer sunk by N. H. Darton, 1900.

[a] Mean annual air temperature at Four Bear, 10 miles west, plus 0.3° for lower altitude.
[b] Newcastle average.

All these figures are correct, and no vitiating conditions are indicated. The Cambria and Newcastle wells were full of water. The steep gradient of the Newcastle well is inexplicable.

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